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THE USE OF COMMERCIAL LOW EARTH ORBIT SATELLITE SYSTEMS TO SUPPORT DOD COMMUNICATIONS

by

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December, 1996

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Within the next five years there will be a proliferation of commercial Low Earth Orbit (LEO) satellite systems providing voice/data services to anywhere in the world. Instead of investing heavily in new satellite systems, the military services can use these forthcoming commercial satellite systems to enhance their existing satellite-based systems. An in-depth study and detailed summary is provided in this thesis for each of the following four commercial LEO satellite systems: Iridium, Teledesic, Odyssey, and Globalstar. Then, a comparison of these systems is performed from the military point of view by using criteria such as antijam protection, security, mobility, flexibility, interoperability, coverage, and capacity. It is shown that an architecture consisting of Globalstar and Odyssey has the potential to provide communications support for DoD's less critical needs which include administration, logistics, and other support functions. Finally, other military applications of these systems are given.

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THE USE OF COMMERCIAL LOW EARTH ORBIT SATELLITE SYSTEMS TO SUPPORT DOD COMMUNICATIONS

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ABSTRACT

Within the next five years there will be a proliferation of commercial Low Earth Orbit (LEO) satellite systems providing voice/data services to anywhere in the world. Instead of investing heavily in new satellite systems, the military services can use these forthcoming commercial satellite systems to enhance their existing satellite-based systems. An in-depth study and detailed summary is provided in this thesis for each of the following four commercial LEO satellite systems: Iridium, Teledesic, Odyssey, and Globalstar. Then, a comparison of these systems is performed from the military point of view by using criteria such as antijam protection, security, mobility, flexibility, interoperability, coverage, and capacity. It is shown that an architecture consisting of Globalstar and Odyssey has the potential to provide communications support for DOD's less critical needs which include administration, logistics, and other support functions. Finally, other military applications of these systems are given.

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LIST OF SYMBOLS, ACRONYMS AND/OR ABBREVIATIONS

ACE	Aviation Combat Element
AFSATCOM	Air Force SATellite COMmunications
ATDMA	Asynchronous Time Division Multiple Access
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
B-ISDN	Broadband Integrated Services Digital Network
bps	bits per second
C2	Command & Control
C&R	Coordination and Reporting
CCO	Constellation Control Operation
CDMA	Code Division Multiple Access
CE	Command Element
COCC	Constellation Operations Control Center
CONUS	Contiguous United States
CSSE	Combat Service Support Element
CVBG	Carrier Battle Group
DSCS	Defense Satellite Communication System
DoD	Department of Defense
ECCM	Electronic Counter Counter Measures
ECM	Electronic Counter Measures
EHF	Extremely High Frequency
ES	Earth Station
FCC	Federal Communications Commission
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FEBA	Forward Edge of Battle Area
FLTSATCOM	FLeeT SATellite COMmunication
FSS	Fixed Satellite Services
Gbps	Giga bits per second
GCE	Ground Combat Element
GEO	Geostationary Earth Orbit
GMF	Ground Mobile Forces
HDR	High Data Rate
IF	Intermediate Frequency
ISDN	Integrated Services Digital Network
ISU	Iridium Subscriber Unit
JTIDS	Joint Tactical Information Distribution System
Kbps	Kilo bits per second
LAN	Local Area Network
LDR	Low Data Rate
LEN	Large Extension Node
LEO	Low Earth Orbit

LHC	Left Hand Circular
LOS	Line Of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Interception
LQP	Loral Qualcomm Partnership
MAGTF	Marine Air-Ground Task Force
Mbps	Mega bits per second
MDR	Medium Data Rate
MEO	Medium Earth Orbit
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MILSATCOM	MILitary SATellite COMmunications
MSE	Mobile Subscriber Equipment
MSS	Mobile Satellite Services
NC	Node Center
NCC	Network Control Center
NOCC	Network Operation Control Center
PCN	Personal Communication Networks
PCS	Personal Communication Systems
PIN	Personal Identification Number
PLMN	Public Land Mobile Network
PSTN	Public Switch Telephone Network
PTP	Point To Point
QPSK	Quadrature Phase Shift Keying
RAU	Radio Access Unit
RDSS	Radio Determination Satellite Services
RF	Radio Frequency
RHC	Right Hand Circular
SATCOM	SATellite COMmunications
SAW	Surface Acoustic Wave
SEN	Small Extension Node
SHF	Super High Frequency
SINCGARS	SINgle Channel Ground-Airborne Radio System
SOCC	Satellite Operation Control Center
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TT&C	Telemetry, Tracking and Control
TWTA	Traveling Wave Tube Amplifier
UAV	Unmanned Air Vehicle
UHF	Ultra High Frequency
VTC	VideoTeleConference
WAN	Wide Area Network

I. INTRODUCTION

In little more than two decades, communications satellite technology has gone from being revolutionary to commonplace, from an idea to world wide service. In both industrialized and developing countries, economic and social progress depends on improved telecommunications. Today, several commercial systems have been proposed (being built) to provide for the global communication of the mobile users using clusters of smaller, less complex satellites in low earth (LEO) and medium earth orbits (MEO). Mobile satellite systems are the future of the satellite communications technology applications. [Ref. 6]

A. CURRENT AND PROPOSED SATELLITE SYSTEMS

Three types of satellite-based communication systems are currently being proposed. The fundamental difference among them lies in the altitude at which the satellites orbit the earth.

1. Geostationary Satellite Systems

The satellites of these systems sit at an orbit altitude of about 36,000 km and as few as three or four satellites are enough for global equatorial coverage. For many years, communication satellites have been maintained in GEO so that the ground antennas could point to a fixed location because of their twenty-four hours period. However, geostationary orbits have several disadvantages including the high cost of placing the

satellites in orbit, significant propagation delays due to the high altitude of the satellites, poor visibility for regions of mid latitude and above, high power levels on board the satellites in order to relay information back to earth, and high gain antennas at earth stations. [Ref. 25]

2. Low Earth Orbit Satellite Systems

A LEO satellite system consists of a constellation of a number of satellites in circular orbits, at altitudes between five hundred to two thousand kilometers. LEO systems have the following advantages: the cost and complexity of launching satellites is moderate; the propagation delay is minimal; power requirements of both satellites and ground stations are minimized. Therefore, handheld terminals can be used for global personal communications. [Ref. 25]

3. Medium Earth Orbit Satellite Systems

Medium-earth orbit systems are a compromise between LEO and GEO systems. The altitude of the orbit is about 10,000 km. These systems require fewer and less complex satellites than the LEO systems. Signal propagation delays, power requirements, and antenna gains are more acceptable than GEO systems. [Ref. 6]

B. RESEARCH

Within the next few years there will be a few LEO satellite systems providing voice/data services anywhere in the world. On the other hand, due to budget cuts and fiscal constraints, it is beneficial for the military to use the forthcoming commercial

LEO/MEO systems to meet the information requirements of the tactical commanders. This thesis attempts to formulate a concept of operations on how the military services can effectively leverage the worldwide capability of commercial LEO/MEO systems.

A detailed summary of four commercial satellite systems (Iridium, Teledesic, Odyssey, and Globalstar) is provided. These systems were chosen because they have been granted licenses by the Federal Communications Commission (Iridium, Odyssey, Globastar) or are in the process of acquiring a license (Teledesic). Then a comparison is performed to identify strengths and weaknesses in their militarization. Finally, the military applications of these systems are given.

II. IRIDIUM

A. INTRODUCTION

In June 1990 Motorola announced the development of its Iridium mobile satellite system which envisions the use of very small low earth orbit satellites to provide worldwide cellular personal communications services. Subscribers to this system will use portable or mobile transceivers with low profile antennas to reach a constellation of 66 satellites (the system design originally consisted of 77 satellites and the project name was selected because the element Iridium has atomic number 77)(see Figure 2.1). These satellites will be interconnected to one another by radio communications as they traverse the globe approximately 420 nautical miles (780 km) above the earth in six near-polar orbits. Principles of cellular diversity are used to provide continuous line-of-sight coverage from and to virtually any point on the earth's surfaces, as well as all points within an altitude of 100,000 feet above mean sea level, with spot beams providing substantial and unprecedented frequency reuse.

As a global communications satellite system with worldwide continuous coverage, Iridium can offer the full range of mobile communications services including radiodetermination, two-way voice and data, on land , in the air, and on water. Any subscriber unit will be able to communicate with any other Iridium subscriber unit (ISU) anywhere in the world, or with any telephone connected to the public switched telephone network (PSTN) (see Figure 2.2).

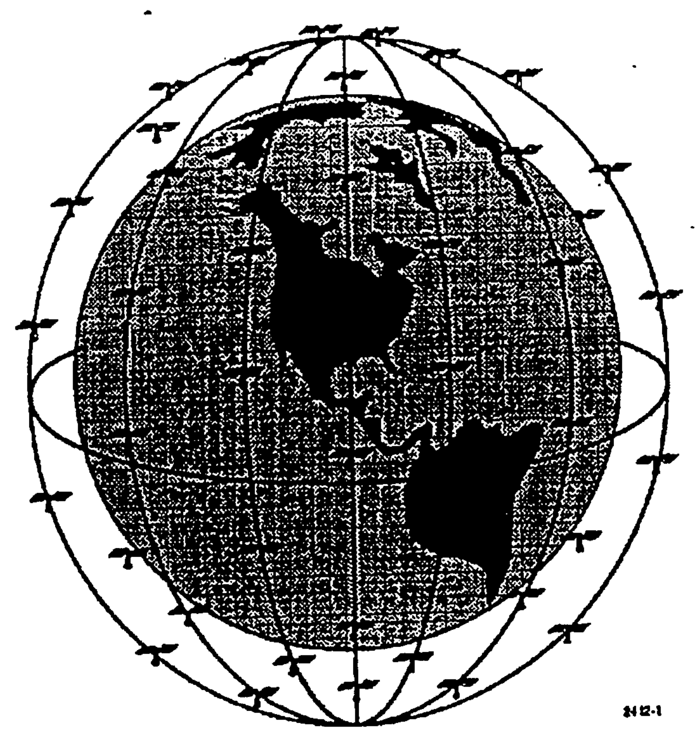


Figure 2.1 Iridium's Satellite Constellation From Ref. [14]

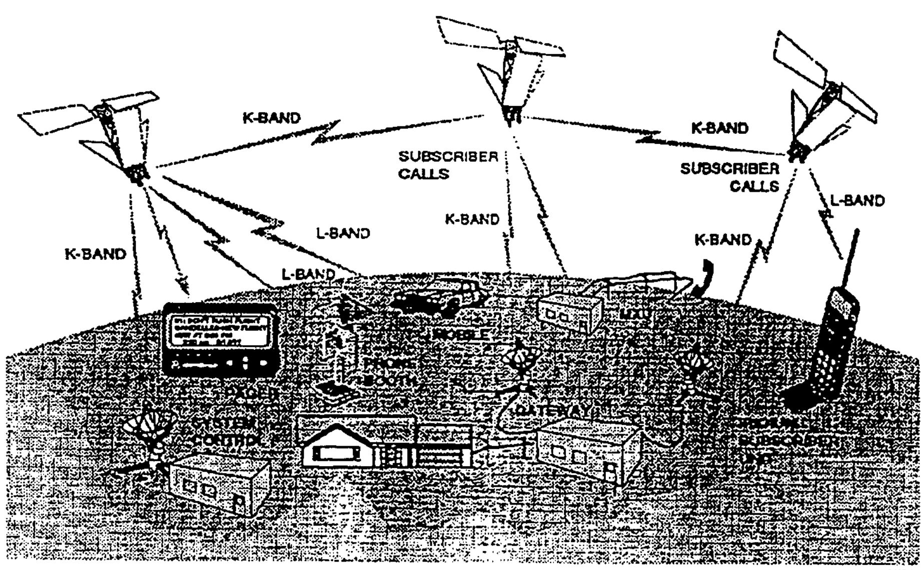


Figure 2.2 The Iridium System Overview From Ref. [14]

B. MARKETS AND PROPOSED SERVICES

Bulk transmission capacity on the Iridium system will be provided to licensed and authorized carriers, who in turn will sell mobile communications to the public in their authorized areas. Due to its limited capacity and cost structure, Iridium is not designed to compete with existing landline and terrestrial based cellular mobile systems. Instead, Iridium will target markets not currently served by mobile communications services, such as

1. sparsely populated locations where there is insufficient demand to justify constructing terrestrial telephone systems

2. areas in many developing countries with no existing telephone service, and

3. small urban areas that do not now have a terrestrial mobile communications structure.

Iridium will provide mobile communications services to the entire United States, including all of its territories and possessions. In addition, Iridium will extend the reach of modern, reliable telecommunications services to and from all worldwide locations. It will offer the full range of mobile services including radiodetermination satellite services (RDSS), paging, messaging, voice, facsimile and data services.

C. SYSTEM DESCRIPTION

1. Space Segment

a. Constellation

The system consists of a constellation of 66 low-earth orbit satellites in six near-polar orbits, with eleven satellites equally spaced in each orbital plane. The apogee is 787 km, the perigee is 768 km, and the inclination angle is 86.4^0. The satellites within each plane are spaced 32.7 degrees apart, and travel at the same direction at approximately 16,669 miles per hour in a north/south direction and 900 miles per hour westward over the equator. Each satellite circles the earth every 100 minutes. In addition up to 12 in-orbit spare satellites will be launched into a near polar orbit approximately 645 km above the earth. Initially, only seven in-orbit spares will be constructed and launched with the 66 operational satellites.

The six planes of satellites co-rotate towards the north pole on one side of the earth and "crossover" and come down towards the south pole on the other side of the earth. Of course, the earth continues to rotate beneath the constellation. The 11 satellites in each plane are equally spaced around their planar orbit, with the satellites in the odd numbered planes (1,3, and 5) in phase with one another, and those in the even numbered planes (2,4, and 6) in phase with each other and halfway out of phase with the odd numbered planes. In order to prevent the satellites from colliding at the poles, a minimum miss distance is maintained between the planes in phase. Each of the six co-rotating planes are separated by 31.6 degrees, and the "seam" between planes 1 and 6, which

represents plane 1 satellites going up on one side of the earth and plane 6 satellites coming down in the adjacent plane, is separated by 22 degrees.

This satellite constellation provides coverage over the entire surface of the earth with single coverage provided at the equator and increasing levels of coverage as the satellites move towards the poles (due to individual satellite coverages beginning to overlap).

b. Frequency Plan

Iridium provides L-band (1616-1626.5 MHz) communications between each satellite and individual subscriber units, Ka-band (uplink 29.1-29.3 GHz, downlink 19.4-19.6 GHz) communications between each spacecraft and ground-based facilities, and Ka-band (23.18-23.38 GHz) crosslinks from satellite to satellite.

(1) L-band Subscriber Links. Subscriber units communicate with the satellites (when the specific area is not served by a terrestrial cellular system) in L-band. Motorola asked for 10.5 MHz bandwidth (1616-1626.5 MHz) for uplink and downlink subscriber links using a combination of TDMA and FDMA. The frequency plan for L-band is shown in Figure 2.3. The channel bandwidth is 31.5 KHz and the channel spacing 41.67 KHz. The polarization will be righthand circular.

(2) Gateway Links. The Ka-band gateway links support simultaneous communications with two ground-based gateways per satellite. Multiple antennas separated by up to 34 nautical miles provide spatial diversity which avoids sun interference and helps mitigate rain attenuation. This provides link availability of 99.8% for gateways.The polarization is circular (lefthand for downlink and righthand for uplink).

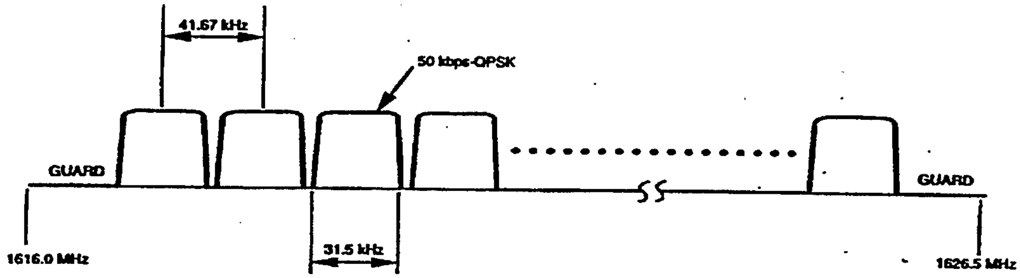


Figure 2.3 L-Band Uplink/Downlink R.F. Frequency Plan From Ref. [15]

(3) Intersatellite Crosslinks. Each satellite operates crosslinks as a medium used to support internetting. These crosslinks operate in the Ka-band (23.18-23.38 GHz) and include both forward and backward looking links to the adjacent satellites in the same orbital plane which are nominally at a fixed angle and 2,173 nautical miles away. Up to 4 interplane crosslinks are also maintained and these links vary in angle and distance from the satellite. Crosslink beams never intercept the earth. The polarization will be horizontal.

c. Frequency Reuse/Cell Management

The constellation of satellites and its projection of cells is somewhat analogous to a cellular telephone system. In the case of cellular telephones a static set of cells serves a large number of mobile users. In the case of Iridium, the users move at slow pace relative to the spacecraft, so the users appear static while the cells move.

Each satellite will utilize up to 48 separate spot-beams to form cells on the surface of the earth. Multiple relatively small beams allow to use the higher satellite antenna gains and reduce the RF power required in the satellite and the user terminal. The spatial separation of the beams allows increased spectral efficiency via time/

frequency/spatial reuse over multiple cells, enabling many simultaneous user messages over the same frequency channel.

The constellation has a potential beam service capacity of 3,168 beams. The full satellite beam capacity is utilized to provide effective continuous coverage near the equator, while fewer beams are required at higher latitudes. Beam shut-down techniques are used to provide a uniform beam density upon the earth's surface.

On a global basis, the entire constellation's beam pattern as projected on the surface of the Earth results in approximately 2,150 active beams with a frequency reuse of about 180 times. Within contiguous United States, the system will achieve about five times frequency reuse.

d. System Capacity

The multiple access format for Iridium uses both time division (TDMA) and frequency division (FDMA) which results in a very efficient use of spectrum. The TDMA format is shown in Figure 2.4. The peak capacity in any given beam over 10.5 MHz of L-band frequency spectrum is 960 channels of which 780 are full duplex voice channels. The contiguous U.S. is covered by approximately 59 beams which yield a capacity of 4,720 channels of which 3,835 are full duplex voice channels.

The end-to-end bit error rate will be better than 10^{-2} for digital voice transmission with a rate of 4800 bps. Basic data services will be accomodated with a rate of 2400 bps and bit error rate of 10^{-3}. The estimated minimum lifetime of an in-orbit satellite is five years.

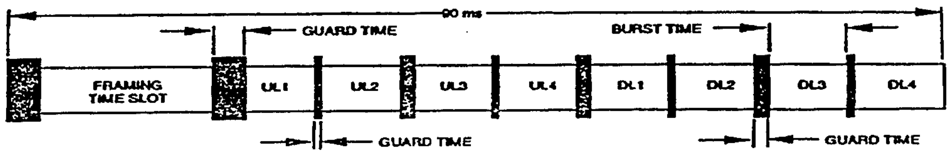


Figure 2.4 TDMA Frame Format From Ref. [15]

e. *Transmission Characteristics*

Iridium has been designed to provide RDSS plus voice and data services using digital transmission in a combined time and frequency division multiplexing scheme. RDSS is accomplished by performing an electronic calculation of the stationary position of the ISU relative to a satellite orbit. Given these results and a description of the satellite orbit, the position of the subscriber's unit can be determined to within one mile. Voice is provided by the transmission of the output of a VSELP 4800 bps voice coder. Processing by this type of voice coder produces discrete blocks or packets of data at the coder framing rate. Each information packet will be protected from errors with a combination of forward error correction and error detection which increase the information bit rate of 4800 bps to a link transmission rate of about 8500 bps.

The system will use differentially encoded, raised cosine filtered, quadrature phase shift keying (QPSK) modulation. This specific format has been chosen as the best compromise for the transmission channel between the satellites and the earth which may experience a combination of multipath fading and transmission impairments (shadowing) due to natural vegetation. Raised cosine filtering of the digital signal reduces

the spectral occupancy and thus permits multiple carriers to be placed close together with acceptable levels of intermodulation.

2. Ground Segment

The ground segment consists of earth stations and associated facilities distributed throughout the world to support call processing operations, control the constellation, and to provide connection to the public switched telephone network (PSTN).

a. Gateways

The gateway segment controls user access and provides interconnection to the terrestrial PSTN. There will be multiple gateways distributed throughout the world. Each gateway contains an earth terminal and switching equipment necessary to support Iridium's mission operations.

Each earth gateway terminal contains three RF front-ends supporting continuous operations with extremely high reliability. One RF front-end is used to establish uplink and downlink communication with the "active" satellite while another is used to establish communication with the next "active" satellite. A third RF front-end provides backup capability in case of equipment failure and also provides geographic diversity against unusual sun or atmospheric conditions that would degrade service. Each RF front-end consists of a Ka-band antenna, receiver, transmitter, demodulator, modulator, and TDMA buffers.

Since the satellites are in motion relative to gateways, both primary antennas follow the track of the nearest two satellites. The communication payload being

conveyed across the "active" link must be handed off periodically, from the current satellite to the next one as the active link disappears from view. This hand-off process will be transparent to both Iridium and PSTN users involved in active calls.

Each gateway provides switching equipment to interface between the communication payload in the Ka-band link and the voice/data channels of the PSTN for establishing, maintaining, and terminating calls.

Each satellite can communicate with earth-based gateways either directly or through other satellites by means of crosslink network. The system architecture is designed to accommodate about 250 independent gateways.

b. System Control Facility

Obviously, there has to be control over these satellites. This is to be performed in the system control facility and functions performed by this facility fall into two general areas; active control of the satellites, and control of the communications assets of the satellites. These tasks are performed by two separate, collocated subsystems.

(1) Constellation Operations. The primary functions of this subsystem are; to manage each satellite's orbit, to monitor each satellite's health, to support satellite launch and checkout, and to remove satellites from the constellation.

(2) Network Operations. This subsystem provides the capability to manage the communications network. Under normal conditions the network will be autonomous, but in the event of abnormal conditions this subsystem will provide instructions to the network nodes on what steps to take to maintain service quality.

Two system control facilities, geographically separated, will be built to help assure continuous operation. The master control facility will be located in Virginia near Washington, DC and the back up control facility in Italy.

3. Subscriber Unit Segment

Three types of ISU (Iridium Subscriber Unit) will be offered; portable/hand-held, mobile, and transportable. The mobile unit can be installed in an automobile or boat and the transportable can be moved between remote fixed locations. Each type of unit will place a call to the nearest satellite. These units are to be compatible with both a user's local terrestrial system as well as the Iridium system. Where the user's terrestrial system is available at home or as a roamer, the user could use the terrestrial system. Where a terrestrial system is not available, barring regulatory restrictions, an Iridium dial tone should be available.

The portable/hand-held unit is currently designed to operate for 24 hours on a single recharge in a combination of standby (able to receive a "ring" indicating an incoming call) and active modes. The system now is being designed to operated with ISU transmit power levels comparable to those of hand-held cellular telephones.

Communications between the ISU and the satellite is over a full-duplex FDMA channel in TDMA bursts of QPSK modulated digital data. Digitized voice is encoded and decoded using the Motorola 4800bps VSELP vocoder algorithm. Subscriber 2400 baud data and 4800 bps digital voice data are protected with convolutional coding and interleaving.

ISU uplink TDMA burst timing is synchronized to the downlink burst. The ISU compensates for changes in satellite range by timing the uplink burst transmission to arrive at the satellite with correct TDMA frame alignment. The ISU also compensates for the satellite Doppler frequency shift by adjusting the uplink transmit frequency.

D. SUMMARY

The Iridium communications system is to be a global, digital, satellite-based, personal communivations system primarily intended to provide low-density, portable service via hand-held subscriber units, employing low-profile antennas. Calls could be made and received anywhere in the world with a personal pocket-sized, portable unit. A constellation of small satellites are to be internetted to form the network's backbone. Small, battery powered, cellular-telephone-like user units are to communicate directly with the satellites. Terrestrial gateways are to interface the satellite network with the public switched telephone network. The system is intented to complement the terrestrial telephone network in densely populated areas by providing a similar service everywhere in the world.

III. TELEDESIC

A. INTRODUCTION

Teledesic Corporation plans to construct a global network of 840 low earth orbit (LEO) satellites operating in Ka-band (30/20 GHz), that will help deliver a wide array of affordable, yet advanced, interactive broadband information services to people in rural and remote parts of the United States and the world. Open and ubiquitous, like a "Global Internet", the Teledesic Network will offer a means of providing a wide range of information services, from high-quality voice channels to broadband channels supporting videoconferencing, interactive multimedia, and real-time, two-way digital data. It will provide "bandwidth on demand", allowing users to adjust their channel capacity from one moment to the next to accommodate their various applications.

The Teledesic Network will be fully interoperable with public networks in the United States and abroad. Teledesic will operate as a non-common carrier and will not market its services directly to users. Rather, it will provide an open platform for service providers in the United States and in host countries to bring affordable access to rural and remote locations.

B. MARKETS AND PROPOSED SERVICES

The benefits to be derived from such services are as vast as the areas of need to which they can extend. With universal access to interactive broadband capabilities, information can flow freely between people, creating wider communities of interest and

support. In the field of health care, for example, doctors and other caregivers can consult with specialists thousands of miles away, share medical records and x-rays, relay critical medical information during epidemics, distribute globally the latest medical research, ensure priority routing of medical supplies during disaster relief programs, and provide remote instruction in nutrition, sanitation, and prenatal and infant care.

The interactive broadband capabilities of the Teledesic Network, coupled with its wireless access technology, also hold the promise of delivering distance learning services to the most remote parts of the United States and the world, thereby offering meaningful educational opportunities to people who would otherwise be cut off -either economically or geographically- from traditional centers of learning.

Advanced technologies have revolutionized the way people exchange and process information in urban areas of the United States and other developed nations. But there is a broader, unmet need. Today, the cost to bring modern communications to poor and remote areas is so high that many of the world's people cannot participate in the global community. Yet the benefits of the communications revolution should be extended to all of the world's citizens, including those who do not reside in or near centers of commerce or industry, who do not have access to doctors, hospitals, schools, or libraries, and who are at risk of being shunted aside. Teledesic hopes to inspire an effort to serve these people.

C. SPACE SEGMENT

1. Constellation

The Teledesic constellation is organized into 21 circular orbit planes that are staggered in altitude between 695 and 705 km. Each plane contains a minimum of 40 operational satellites plus up to four on-orbit spares spaced evenly around the orbit. The orbit planes are at a sun-synchronous inclination (approximately 98.2^0), which keeps them at a constant angle relative to the sun. The ascending nodes of adjacent orbit planes are spaced at 9.5^0 around the equator (see Figure 3.1). Satellites in adjacent planes travel in the same direction except at the constellation "seams", where ascending and descending portions of the orbits overlap. There is no fixed phase relation between satellites in adjacent planes; the position of a satellite in one orbit is decoupled from those in other orbits.

The Teledesic constellation is designed to ensure that there is always at least one satellite above a 40^0 elevation angle over the entire coverage area. Coverage is provided twenty-four hours a day between 72^0 north and south latitude, with partial day coverage to higher latitudes (that is, 95% of the Earth's surface and almost 100% of its population). Also, the altitudes of satellites in different orbit planes are staggered to eliminate the possibility of collision between satellites in crossing orbits. The nominal 700 km altitude and 40^0 elevation mask angle yield a satellite footprint approximately 1400 km in diameter. Teledesic's minimum of 40 satellites per plane and 9.5^0 spacing between planes

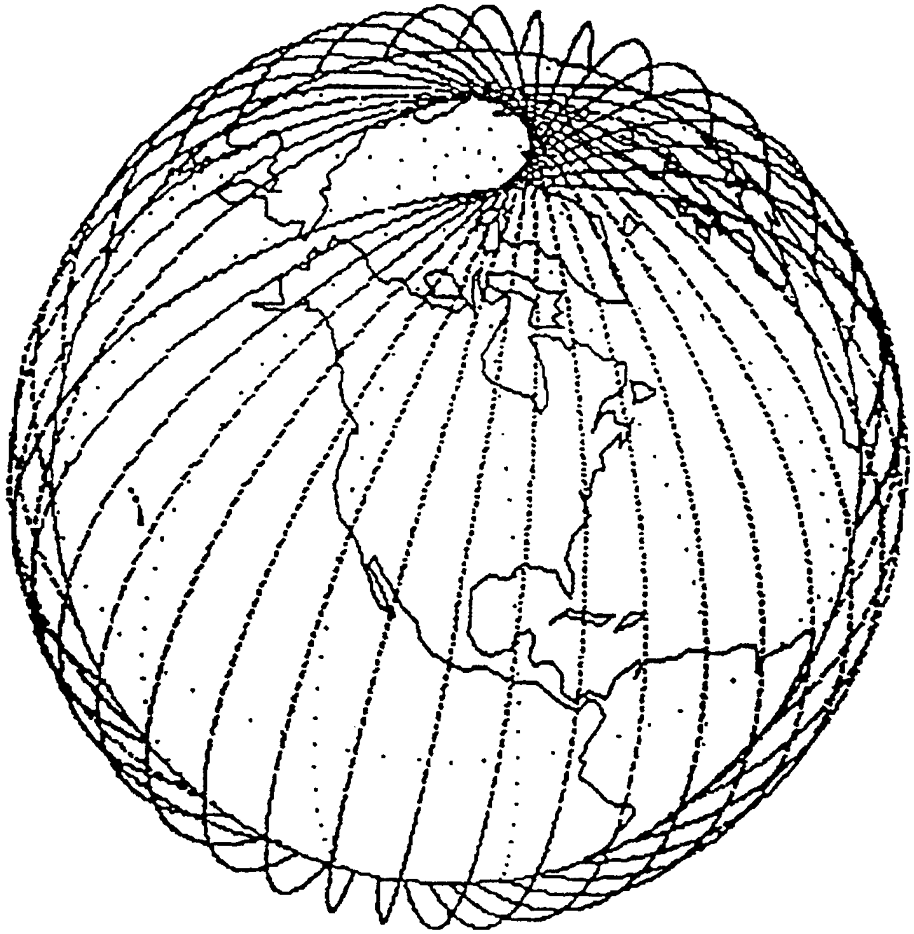


Figure 3.1 Teledesic's Orbits From Ref. [17]

provides a high degree of coverage redundancy and allows satellites in one plane to be repositioned without opening coverage gaps between planes. Figure 3.2 illustrates the coverage redundancy over the continental United States. These constellation characteristics reduce both the effect of a satellite failure and the time to "repair" the constellation. If a satellite failure causes a coverage gap, it can be filled within two hours by repositioning the satellites in that plane.

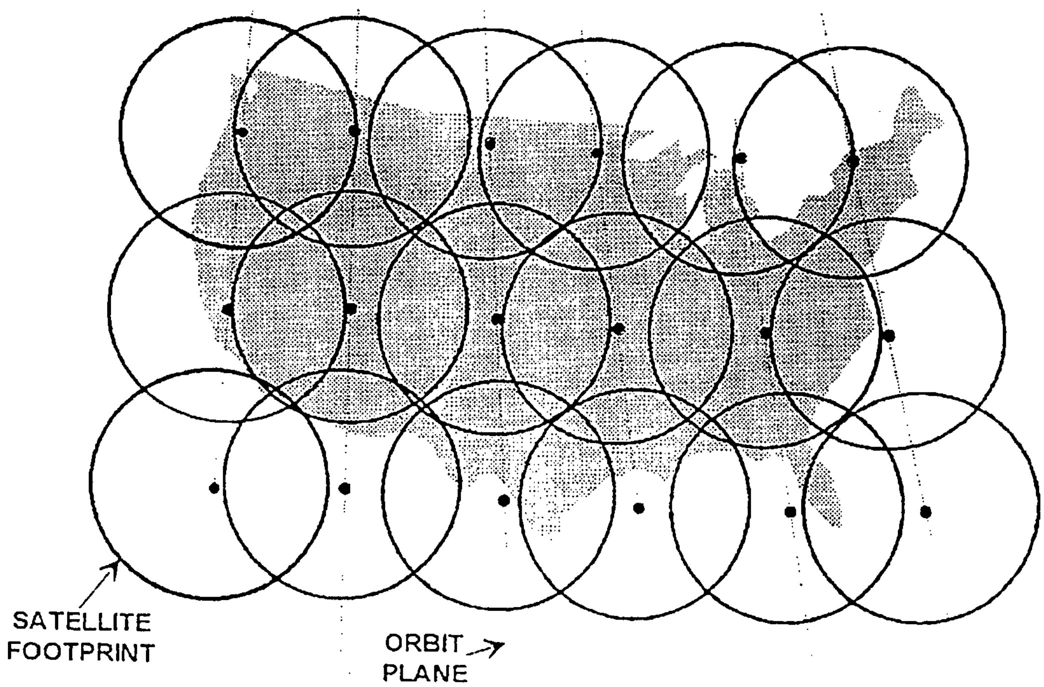


Figure 3.2 Teledesic's Footprint Coverage Over the Continental U.S. From Ref. [17]

2. The Satellites

The on-orbit configuration of the Teledesic satellite resembles a flower with eight "petals" with a large boom-mounted-square solar array as shown in Figure 3.3. The deployed satellite is 12 m in diameter and the solar array is 12 m on each side. Each petal consists of three large electronically-steered phased-array antenna panels with integrated transmit, receive, and ancillary electronics. The octagonal baseplate also supports eight pairs of intersatellite link antennas, the two satellite bus structures that house the engineering subsystem components, and propulsion thrusters. A third satellite bus structure, containing power equipment and additional propulsion thrusters, is mounted at the end of the solar array boom. The solar array is articulated to point to the sun.

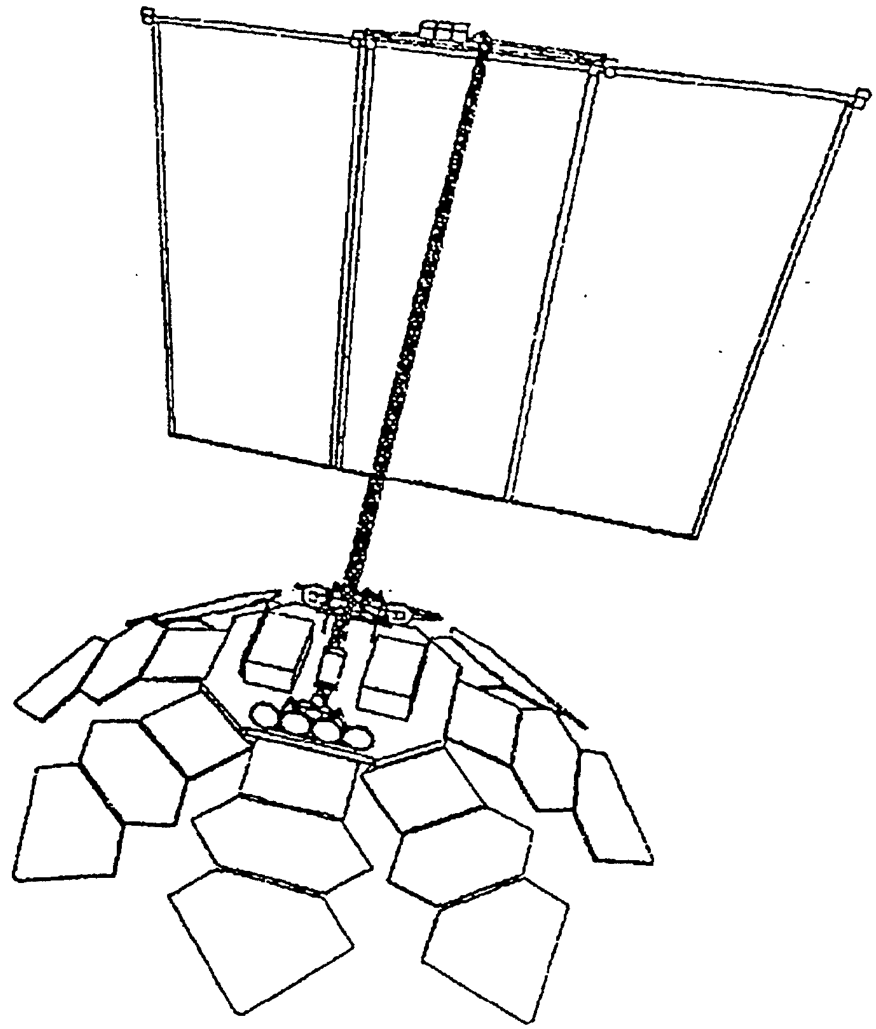


Figure 3.3 The Teledesic Satellite From Ref. [17]

The estimated on orbit lifetime of each satellite is 10 years. Degradables and consumables (i.e., solar array, batteries, propellant, etc.) have been sized to exceed the 10 year operational lifetime. Each satellite carries over twice the propellant needed to insert itself into its orbital position, to overcome atmospheric drag for its design lifetime (including one solar maximum), to reposition itself when required, and to perform a final deorbit maneuver.

D. THE NETWORK

1. General Description

The Teledesic Network provides a quality of service comparable to today's modern terrestrial communication systems, including fiber-like delays, bit error rates less than 10^{-9}, and a link availability of 99.9% over most of the United States. The 16 Kbps basic channel rate supports low-delay voice coding that meets "network quality" standards. A variety of terminals accommodate "on-demand" channel rates from 16 Kbps up to 2.048 Mbps (E1), and for special applications up to 1.24416 Gbps (OC-24). This allows a flexible, efficient match between system resources and the requirements of users' diverse applications.

The initial Teledesic constellation has a capacity equivalent to a peak load of more than 2,000,000 simultaneous full-duplex 16 Kbps connections, corresponding to over 20,000,000 users at typical "wireline" business usage levels. The actual user capacity will depend on the average channel rate and occupancy. The system design allows graceful evolution to constellations with much higher capacity without altering the system architecture, spectrum plan or user terminals. The network capacity estimates assume a realistic, non-uniform distribution pattern of users over the earth's land masses; some cells will generate over 100 times the traffic of the "average" cell.

End users will be served by one or more local service providers in the United States and in each host country. Terminals at gateway and user sites communicate directly with Teledesic's satellite-based network and through gateway switches, to terminals on other networks. Figure 3.4 is an overview of Teledesic's Network.

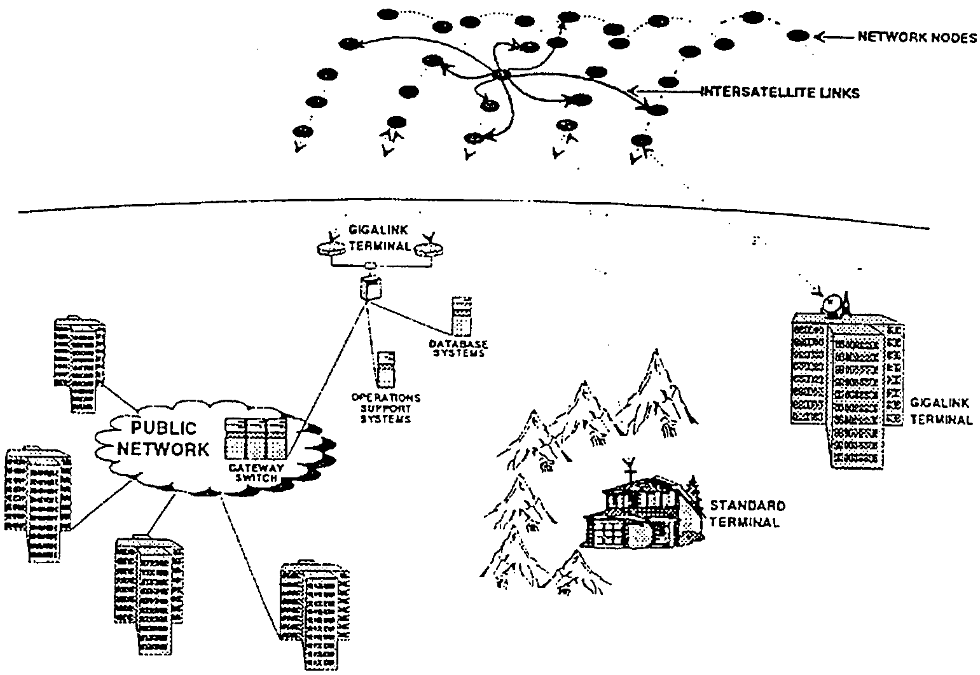


Figure 3.4 The Teledesic Network From Ref. [17]

The network uses fast packet switching technology based on the asynchronous transfer mode (ATM) technology now being used in local area networks (LAN), wide area networks (WAN), and the broadband integrated services digital network (B-ISDN). All communication is treated identically within the network as streams of short fixed-length packets. Each packet contains a header that includes address and sequence information, an error-control section used to verify the integrity of the header, and a payload section that carries the digitally encoded voice or data. Conversion to and from the packet format takes place in the terminals. The fast packet switch network combines the advantages of a circuit-switched network (low delay "digital pipes"), and a packet-switched network (efficient handling of multi-rate and bursty data). Fast packet switching technology is ideally suited for the dynamic nature of a LEO network.

Each satellite in the constellation is a node in the fast packet switch network, and has intersatellite communication links with eight adjacent satellites. Each satellite is normally linked with four satellites within the same plane (two in front and two behind) and with one in each of the two adjacent planes on both sides. Each intersatellite link operates at 155.52 Mbps, and multiple of this rate up to 1.24416 Gbps depending upon the instantaneous capacity requirement. This interconnection arrangement forms a non-hierarchical "geodesic," or mesh, network and provides a robust network configuration that is tolerant to faults and local congestion.

2. Earth-Fixed Cells

The Teledesic Network uses an Earth-fixed cell design to minimize the hand-off problem. The system maps the earth's surface into a fixed grid of approximately 20,000 "supercells", each consisting of nine cells (see Figure 3.5). Each supercell is a square 160 km on each side. Supercells are arranged in bands parallel to the equator. There are approximately 250 supercells in the band at the equator, and the number per band is not constant, the "north-south" supercell borders in adjacent bands are not aligned. A satellite footprint encompasses a maximum of 64 supercells, or 576 cells. The actual number of cells for which a satellite is responsible varies by satellite with its orbital position and its distance from adjacent satellites. In general, the satellite closest to the center of a supercell has coverage responsibility. As a satellite passes over, it steers its antenna beams to the fixed cell locations within its footprint. This beam steering compensates for the satellite's motion as well as the earth's rotation. Channel resources (frequencies and time slots) are associated with each cell and are managed by the current

"serving" satellite. As long as a terminal remains within the same earth-fixed cell, it maintains the same channel assignment for the duration of a call, regardless of how many satellite and beams are involved.Channel reassignments become the exception rather than the normal case, thus eliminating much of the frequency management and hand-off overhead.

A database contained in each satellite defines the type of service allowed within each earth-fixed cell. Small fixed cells allow Teledesic to avoid interference to or from specific geographic areas and to contour service areas to national boundaries. This would be difficult to accomplish with large cells or cells that move with the satellite.

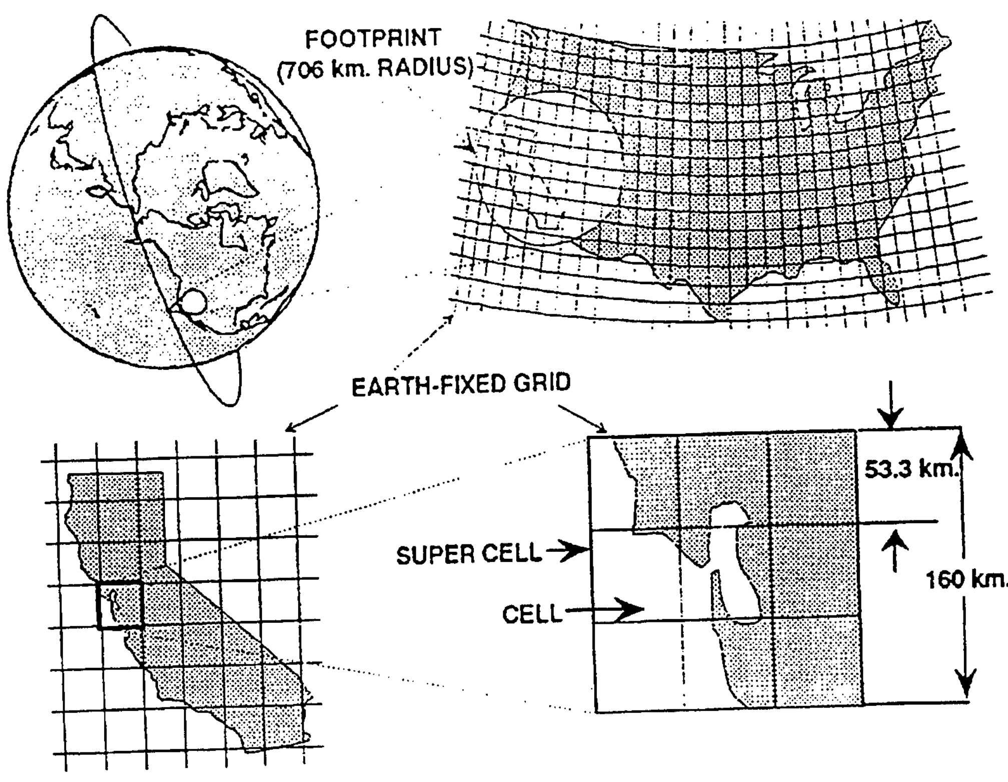


Figure 3.5 Teledesic's Earth-Fixed Cells From Ref. [17]

3. Multiple Access Method

The Teledesic Network uses a combination of multiple access methods to ensure efficient use of the spectrum (see Figure 3.6). Each cell within a supercell is assigned to one of nine equal time slots. All communications take place between the satellite and the terminals in that cell during its assigned time slot. Within each cell's time slot, the full frequency allocation is available to support communication channels. The cells are scanned in a regular cycle by the satellite's transmit and receive beams, resulting in time division multiple access (TDMA) among the cells in a supercell. Since propagation delay varies with path length, satellite transmissions are timed to ensure that cell N (N=1, 2, 3,...9) of all supercells receive transmissions at the same time. Terminal transmissions to a satellite are also timed to ensure that transmissions from the same numbered cell in all supercells in its coverage area reach that satellite at the same time. Physical separation (space division multiple access or SDMA) and a checkerboard pattern of left and right circular polarization eliminate interference between cells scanned at the same time in adjacent supercells. Guard time intervals eliminate overlap between signals received from time-consecutive cells.

Within each cell's time slot, terminals use frequency division multiple access (FDMA) on the uplink and asynchronous time division multiple access (ATDMA) on the downlink. On the uplink, each active terminal is assigned one or more frequency slots for the call's duration and can send one packet per slot each scan period (23.111 msec). The number of slots assigned to a terminal determines its maximum available transmission rate. One slot corresponds to a standard terminal's 16 Kbps basic channel with its

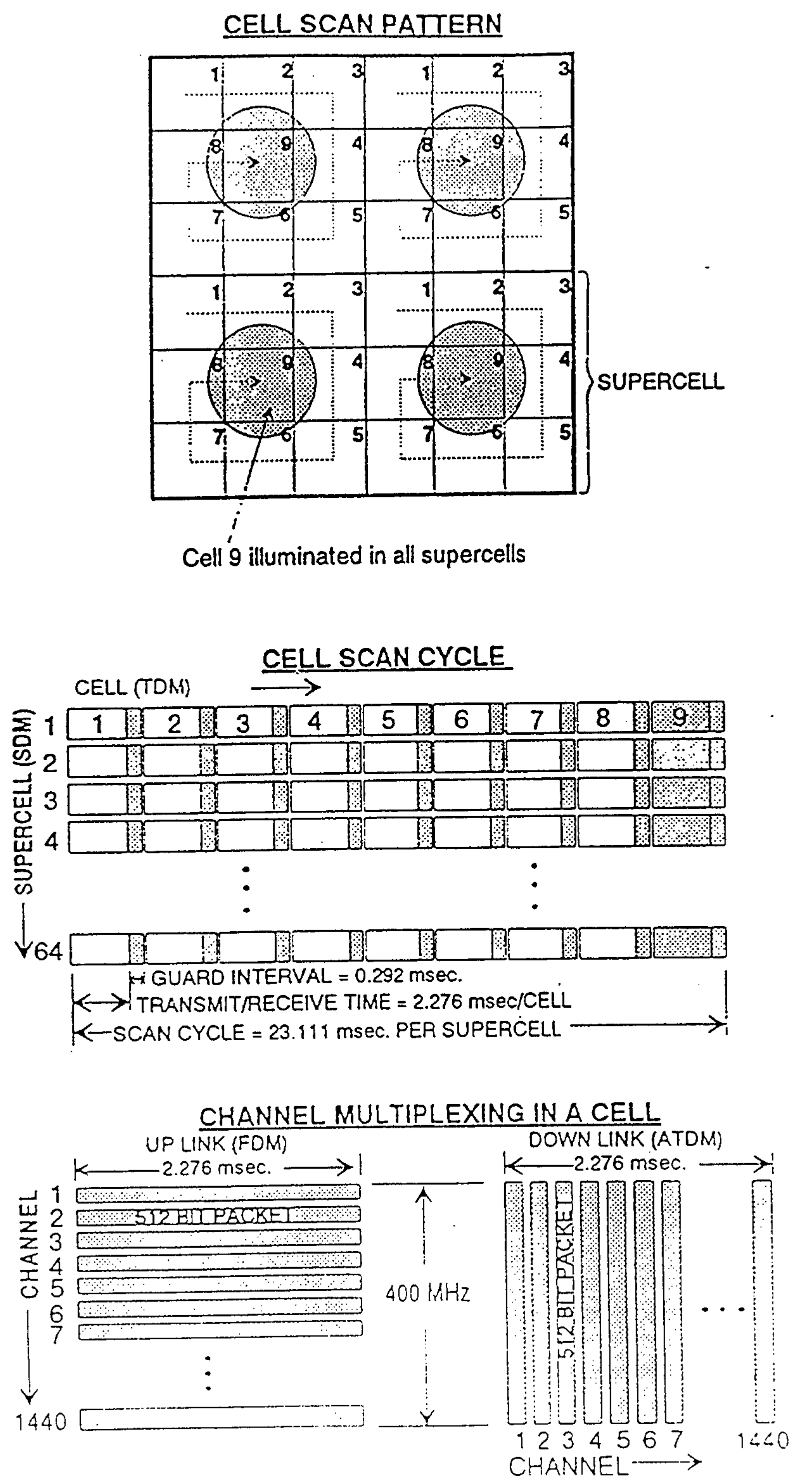


Figure 3.6 Teledesic's Standard Terminal Multiple Access Method From Ref. [17]

associated 2 Kbps signaling and control channel. A total of 1,440 slots per cell scan interval are available for standard terminals.

The terminal downlink uses the packet's header rather than a fixed assignment of time slots to address terminals. During each cell's scan interval the satellite transmits a series of packets addressed to terminals within that cell. Packets are delimited by a unique bit pattern, and a terminal selects those addressed to it by examining each packet's address field. A standard terminal operating at 16 Kbps requires one packet per scan interval. The downlink capacity is 1,440 packets per cell per scan interval. The satellite transmits only as long as it takes to send the packets queued for a cell.

4. Communication Links

All of the Teledesic communications links transport data and voice as fixed-length (512) bit packets. The basic unit of channel capacity is the "basic channel", which supports a 16 Kbps payload data rate and an associated 2 Kbps "D-channel" for signaling and control. Basic channels can be aggregated to support higher data rates. A Teledesic terminal can support multiple simultaneous network connections. In addition, the two directions of a network connection can operate at different rates.

The links are encrypted to guard against eavesdropping. Terminals perform the encryption/decryption and conversion to and from the packet format. The uplinks use dynamic power control of the RF transmitters so that the minimum amount of power is used to carry out the desired communication. Minimum transmitter power is used for clear sky conditions. The transmitter power is increased to compensate for rain.

E. EARTH SEGMENT

The Teledesic Network accommodates a wide variety of terminals and data rates. Standard terminals will include both fixed-site and transportable configurations that operate at multiples of the 16 Kbps basic channel payload rate up to 2.048 Mbps (the equivalent of 128 basic channels). All data rates, up to the full 2.048 Mbps, can be supported with an average transmit power of 0.3 W by suitable choice of antenna size. Within its service area, each satellite can support a combination of terminals with a total throughput equivalent to over 100,000 simultaneous basic channels.

The Network also supports a smaller number of fixed-site gigalink terminals that operate at the OC-3 rate (155.52 Mbps) and multiples of this rate up to OC-24 (1.24416 Gbps). Transmit power will range from 1 W to 49 W depending on antenna diameter, data rate, and climatic conditions. Antenna site-diversity can be used to reduce the probability of rain outage in situations where this is a problem.

Gigalink terminals provide gateway connections to public networks and to Teledesic support and data base systems including network operations and control centers (NOCC) and constellation operations control centers (COCC), as well as to privately owned networks and high-rate terminals. A satellite can support up to sixteen gigalink terminals within its service area.

F. CONTROL SEGMENT

1. Control Functions

The network control hierarchy is distributed among the network elements. Terminals and other network elements use a packet-based protocol for signaling and control. The network handles these "control" packets in the same manner as normal information packets.

The highest levels of network control reside in distributed, ground-based systems that are connected via gigalink terminals to the satellite network. Database systems provide terminal/user feature and service profiles, authentication and encryption keys, call routing data, and other administrative data. Administrative systems, from "network-level" to local "in-country" systems, provide secure access to various levels of the database and billing systems.

High-level call control functions reside in feature processors and gateway switches. The feature processor controls intra-network calls as well as the initial setup of inter-network calls which involve a gateway. Only control and signaling packets are passed to the feature processor; user packets are transmitted through the network over the path of least delay. A gateway switch controls calls that are connected through that switch.

The satellite-based switch node includes some mid-level call control functions in addition to its packet routing function. It manages the assignment, supervision, and release of all channels in its coverage area and the "hand-off" of channels to other

satellites. It also monitors channel signal quality and initiates uplink power control when required.

Terminals control some low-level call control functions similar to those of a cellular or ISDN functional signaling terminal. These functions include user authentication, location registration, link encryption, monitoring and reporting of channel quality, channel assignments and hand-offs, and D-channel signaling.

2. Adaptive Routing

The topology of a LEO-based network is dynamic. Each satellite keeps the same position relative to other satellites in its orbital plane. Its position and propagation delay relative to earth terminals and to satellites in other planes change continuously and predictably. In addition to changes in network topology, as traffic flows through the network, queues of packets accumulate in the satellites, changing the waiting time before transmission to the next satellite. All of these factors affect the packet routing, choice made by the fast packet switch in each satellite. These decisions are made continuously within each node using Teledesic's distributed adaptive routing algorithm. This algorithm uses information transmitted throughout the network by each satellite to "learn" the current status of the network in order to select the path of least delay to a packet's destination. The algorithm also controls the connection and disconnection of intersatellite links.

The network uses a "connectionless" protocol. Packets of the same connection may follow different paths through the network. Each node independently routes the packet along the path that currently offers the least expected delay to its destination. The

required packets are buffered, and if necessary resequenced, at the destination terminal to eliminate the effect of timing variations.

G. SUMMARY

There is a significant worldwide demand for broadband communication capacity. Teledesic plans to meet this demand using a constellation of 840 low earth orbit (LEO) satellites operating in Ka-band. The Teledesic Network provides worldwide bandwidth-on-demand, quality service with bit error rates less than 10^{-9} and fiber-like delays. The data rates are from 16 Kbps (basic channel) up to 2.048 Mbps and for special applications from 155.52 Mbps up to 1.24416 Gbps. Teledesic Corporation hopes to bring the information revolution to people who could not be served economically through existing technologies.

IV. ODYSSEY

A. INTRODUCTION

Today there is a growing demand to provide increased mobile communications for both commercial and personal use. TRW plans to meet this demand with Odyssey. Odyssey is a satellite based communication system bringing world-wide communications ability to the palm of a person's hand. It will provide high quality personal and mobile communications services with a constellation of twelve medium earth orbit (MEO) satellites. These services include voice and data (including messaging).

Communication can be established either between mobile and fixed users or between pairs of mobile users. A dual-mode handset allows the user to communicate either through local cellular networks, when available, or through the Odyssey system when cellular is not present. Odyssey earth stations and associated gateways to the PSTN interconnect mobile (between 70^0 North latitude and 55^0 South latitude) and fixed users around the world via the "bent-pipe" satellite transponders.

B. MARKETS AND PROPOSED SERVICES

Odyssey system will be used by its customers for the provision of high quality satellite capacity, for mobile voice services that will serve the ever-increasing number of cellular "roamers" and other unserved or underserved segments of the burgeoning cellular telephone market, and for the provision of innovative and low-cost data services. End

users of Odyssey capacity would also include any business or commercial entity that has a need to track its inventory or freight carriers and maintain constant communication with its personnel; municipal, local, and state governments that are responsible for the provision of emergency services; and cellular services providers that are interested in augmenting and expanding the coverage areas of their systems.

TRW does not intend to provide space segment on Odyssey directly to end users, but will instead sell or lease space segment capacity in bulk to resellers and others that will, in turn, offer commercial mobile radio services to end users. As a result, TRW is entitled to be regulated as a non-common carrier.

C. SYSTEM DESCRIPTION

An overview of the Odyssey system is illustrated in Figure 4.1. The system basically is composed of a space segment, a ground segment and a handset segment.

1. Space Segment

a. Constellation

The constellation will be comprised of twelve operational satellites in three orbital planes (four satellites per plane) plus two ground spare satellites. The satellite orbits will be circular with an altitude of approximately 10,355 km (see Figure 4.2). The orbital period of the satellites is six hours. The user-to-earth station propagation time delay will range from 68 to 104 milliseconds for mobile to fixed users. Also, the altitude is

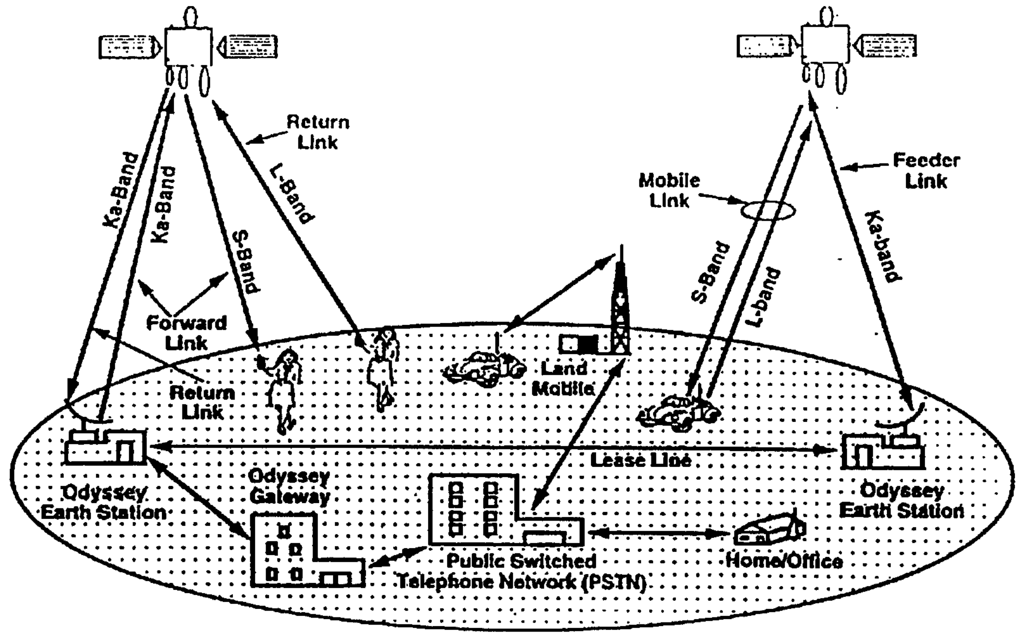
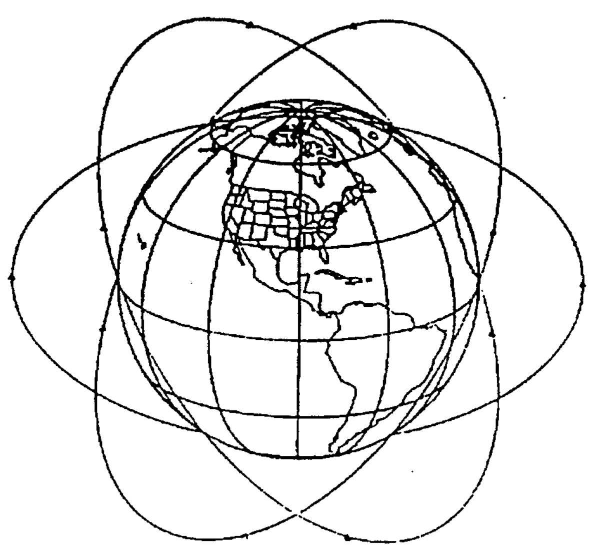


Figure 4.1 Odyssey System Overview From Ref. [19]



- Number of satellites: 12
- Number of planes: 3
- Altitude (circular): 5600 nm (or 10355 Km)
- Inclination: 50°
- Apogee: 5600 nm
- Perigee: 5600 nm
- Argument of Perigee: 0°
- Active Service Arcs: N/A
- Right Ascension of ascending node(s)
  - Reference: 0°, 120°, 240°
  - Varies during life time 0.1° per day

Figure 4.2 Odyssey Satellite Constellation From Ref. [18]

high enough so that the effects of the Van Allen radiation belt are minimal. An additional benefit for system operation is the long time interval (up to an hour and half) during which the satellite is visible to a user and the associated earth station. This minimize the number of intra-call handoffs. The Odyssey constellation of twelve satellites will be deployed by launching two satellites at a time into one of three orbital planes. Twelve satellites will ensure that at least two satellites are visible to any user anywhere in the world. Replacement satellites will be launched as needed.

b. Frequency Plan

(1) L/S-band Links. The forward link includes a Ka-band link from the earth station to the satellite and an S-band link down to the user (see Figure 4.1). The return link from the user to the earth station includes an L-band to the satellite and a Ka-band link down to the earth station. The satellite payload will function as a bent pipe, simple frequency translating transponder receiving and transmitting code division multiple access (CDMA) signals with no on-board signal processing.

The Odyssey system will share with other CDMA systems a bandwidth of 11.35 MHz in both the forward (1610-1621.35 MHz, L-band) and return (2483.5-2494.85 MHz, S-band) user links. This bandwidth will be divided in sub-bands ranging from 0.25 MHz to 2.5 MHz in order to maximize the efficiency of spectrum utilization in areas of high service demand.

(2) Ka-band Links. The mobile link frequency bands are assembled into a frequency division multiplex (FDM) format of 300 MHz bandwidth for transmission on the Ka-band feeder links as shown in Figure 4.3. Circular polarization is

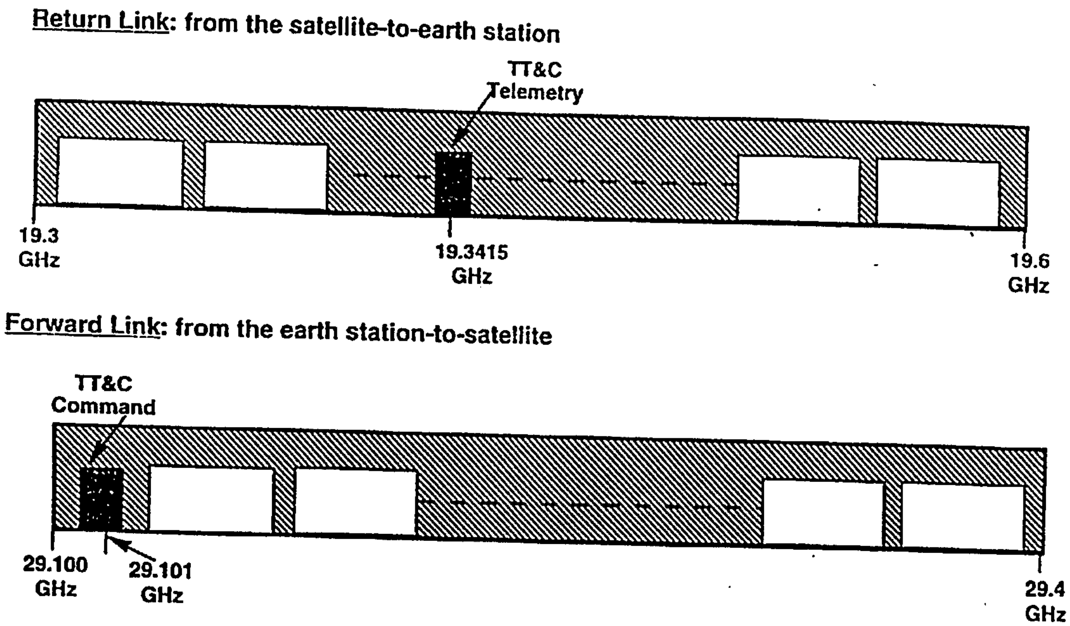


Figure 4.3 Ka-Band Feeder Link Frequency Plan From Ref. [21]

used on all links. Single circular polarization is used due to the degradation of polarization isolation induced by such phenomena as rain.

System signaling will be accomplished using similar CDMA schemes as for voice and data traffic. Forward link signaling will include paging, access, and control messages. Return link signaling will include access and control messages. An optional, premium service for call alerting may use a CDMA signal on the forward link to alert users of an incoming signal if the normal paging process is ineffective due to paging signal degradation inside structures.

The payload can transpond up to 108 individual 2.5 MHz bands spaced 2.75 MHz from band center to band center. A fixed quantity of frequency bands will be permanently assigned to beams. The remaining bands will be switched among the 61 beams to provide extra communication capability to specific geographic locations, as

traffic requires. The filtering will be accomplished by narroband surface acoustic wave (SAW) filters. The filter outputs will be combined into a single 300 MHz FDM signal. The FDM signal will be identically divided three ways, upconverted to the 20 GHz Ka-band downlink frequency and amplified a traveling wave tube amplifier (TWTA). The three redundant TWTAs will each output to a dual band (20 and 30 GHz, Ka-band), circularly polarized narrow beam antenna. Each of the three Ka-band antennas will be indepedently gimbaled and pointed toward earth stations. Since the same signals are to be transmitted by the three Ka-band antennas, up to three downlink footprints will be created, enabling three or more earth stations to simultaneously receive the return link traffic and telemetry.

The 30 GHz band uplink signals will be collected by one or more Ka-band spacecraft receive antennas. The uplink signal has a 300 MHz bandwidth consisting of 108 2.5 MHz FDM bands and the spacecraft command signal. Each antenna's output will be amplified and downconverted to IF. The IF signal from the three receivers will be combined into a single 300 MHz IF signal. The combined IF will be separated into 2.5 MHz using SAW filters. By combining the IF signals of all three antennas and selecting the bandwidth for each mobile link beam, the traffic for a particular beam can originate from any earth station without the need for instantaneous reconfiguration of the payload. A block diagram of the Odyssey payload is shown in Figure 4.4.

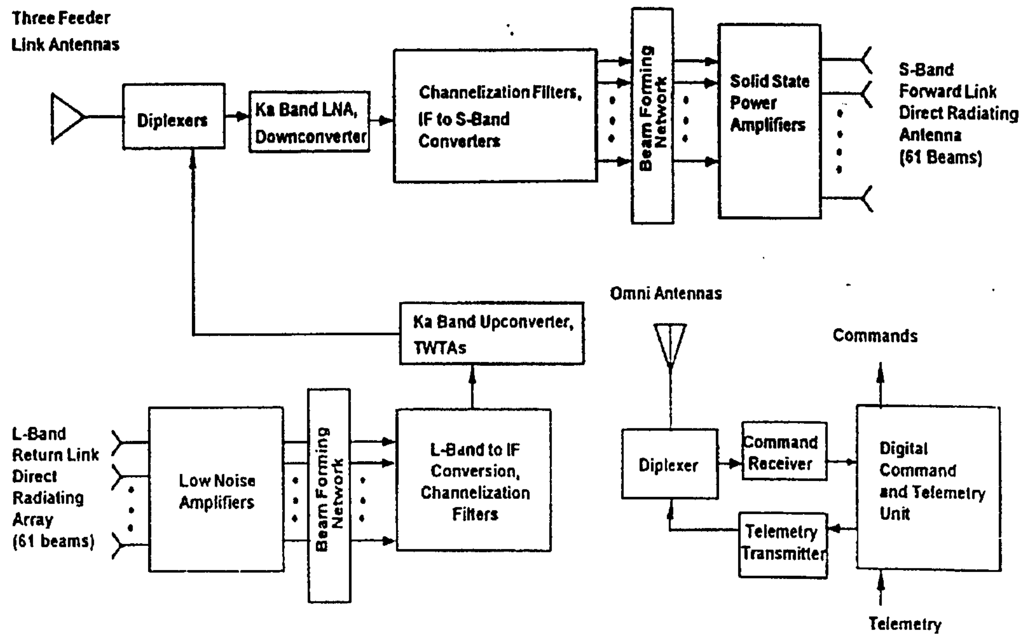


Figure 4.4 Odyssey Payload Block Diagram From Ref. [19]

c. Frequency Reuse/Cell Management

CDMA technology allows for full frequency spectrum reuse over the 61 beams. This essential feature of CDMA, along with the sub-band channelization plan used by Odyssey, permits powerful and dynamic flexibility for traffic management. The sub-band filtering to be used along with CDMA modulation will allow a relatively modest demand on antenna beam spatial isolation requirements since demodulation will spread the interfering spectra and filtering will provide additional interference suppression.

Odyssey constellation is designed to permit dual coverage of the US service region. The 61 beam patterns of two satellites will be overlaid on the region. Thus RF power requirements on individual satellites will be reduced by dividing the required

power for peak traffic periods between a pair of satellites. Frequency assignments will be made so as to maximize satellite and system capacity.

d. System Capacity

Each satellite will have a capacity of 3,000 circuits. This capacity results in economical satellite primary power requirements. Distribution of the 3,000 circuits among the 61 cells will not be uniform. The satellite transmitter complement is designed using matrix amplifier techniques so that each satellite has the capability to support 600 circuits in a "hot spot" beam.

Most regions will be able to take advantage of dual satellite coverage. Dual satellite coverage improves the overall availability of the communication system to a user. Additionally, dual coverage of a region allows 6,000 circuits to serve the region.

Basic digital data service will be accommodated by using a data rate of 2400 bps. Digital data service quality will be assured by maintaining a system BER of 10^{-5} through the use of sophisticated error correction encoding schemes. The voice data rate is 4800 bps with BER 10^{-3}.

e. Transmission Characteristics

Odyssey will provide voice and data services. Voice service at 4800 bps is to be provided by transmission of digitally encoded voice and in-band signaling. Several such voice encoders (vocoders) exist and can be implemented within the processing used at the earth station and handset. Processing by these vocoders produces discrete blocks or packets of data at the coder framing rate. Each information packet is protected from errors

with a combination of a forward error correcting code and interleaving.

Basic data service will be provided by the handset with transmission at the rate of 2400 bps. Forward error correction and interleaving will be used to protect against transmission errors. Higher transmission rate data services maybe provided through more sophisticated user terminals dedicated to this function. Digital modulation using CDMA techniques is employed for both voice and data information.

Spread spectrum CDMA has been chosen for multiple access because it minimizes intersystem interference and allows frequency spectrum sharing. The spread spectrum functions can easily be implemented with microelectronic technology.

Quadrature phase shift keying (QPSK) is the basic signal structure used for waveform modulation. For the voice user, a speech detector within the voice encoder determines when the user is not actively speaking. In this case, the bit rate at handset output will be reduced to the minimum required to maintain the link. This feature increases the channel capacity by nearly a factor of two by taking advantage of the fact that a user will actively be speaking only about one half of the time.

The Odyssey space segment will provide system availability exceeding 99.5% for 10 years. The entire system will feature highly reliable components and subsystems with redundancy implemented throughout, achieving a satellite mean mission duration of 12 years. Expendables are sized for 15 years.

2. Ground Segment

The Ground Segment which will provide user service to the US region and adjacent areas is to be comprised of two earth stations (ES); one in each coast. Each ES

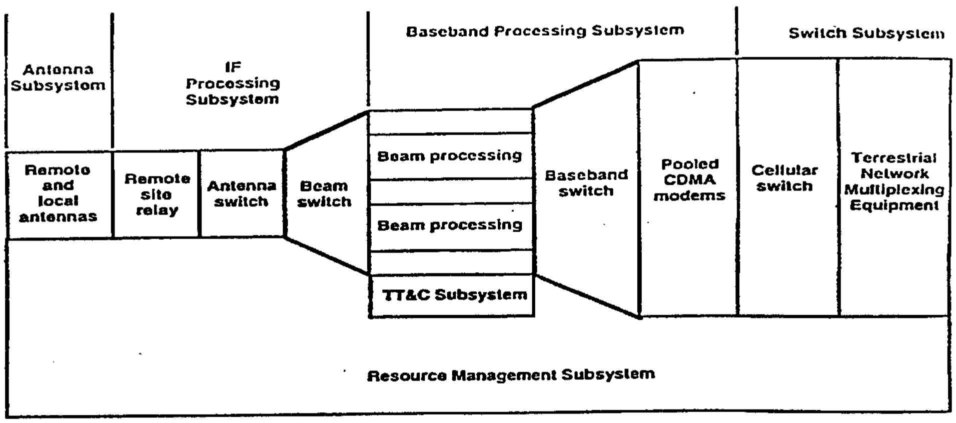


Figure 4.5 Odyssey Ground Station From Ref. [19]

will have the equipment and software to monitor and control the satellite constellation, route user traffic and manage the communication network. Each US region ES is to be comprised of seven equipment groups as illustrated in Figure 4.5. The antenna and RF equipment will be located at the four Ka-band steerable antenna sites which will be geographically mutually dispersed by 10 to 30 km to protect against sun intrusions and atmospheric conditions (primarily heavy rain) which degrade user service. Each ES will always be in contact with two satellites and preparing to transfer operations to a third.

Bulk purchasers/lessees of Odyssey capacity will be able to utilize the earth station to provide connection of voice or data users to either another Odyssey user or to a PSTN user. PSTN interconnection will be provided through a gateway. The gateway will perform all the conversions between the Odyssey formats for voice, data, and signaling to the format of the interconnecting PSTN. Gateways will be located at strategic sites throughout the world to allow users to establish a circuit to any destination worldwide. Connections between two mobile users or between a mobile and a PSTN user

will be accomplished through a digital matrix switch. The common carrier interface, to be located on the PSTN side of the matrix switch, will provide the final multiplexing and protocol interface to the public switched telephone network.

3. Handset Segment

The Odyssey handset is a dual mode design that will support user communication through the Odyssey system and a terrestrial cellular system. Several versions of the handset will be available to support dual mode service with the various terrestrial cellular standards.

Full duplex communication between the handset and the satellite will be provided by modulated digital data using spread spectrum CDMA techniques. Subscriber voice is to be digitized, compressed, formatted, and error correction encoded in the handset and routed to the transmitter section. Basic 2400 bps data service may be input to the handset through a compatible data port in the place of voiced data. This data will be formatted and encoded into a data stream. The data stream will then be used to modulate the L-band uplink carrier. The user received S-band signal is to undergo the reverse processing to deliver either voice or digital data to the subscriber.

The protocol between the handset and the ground station is similar to that used for a typical cellular system to the greatest extent possible. The protocols for placing a call, call setup, handover, termination, and other administrative functions have been modeled after the terrestrial cellular systems. Handsets are similar to cellular ones and will conform to their size, weight and power. The average power will be less than 0.5 W, the polarization circular, and the modulation QPSK (see Table 4.1).

	Transmit (Uplink)	Receive (Downlink)
Frequency	1610.0-1626.5 MHz	2483.5-2500.0 MHz
Signal Polarization	RHCP	RHCP
Output Power Amplifier (Input To Antenna)	1.4 W-Peak Max less than 0.5W average	N/A
Antenna * Type * Gain * Area of Coverage	 Quadrifliar helix or equiv. $0.0 \rightarrow 1.5$ dBi $20^0 \rightarrow 90^0$ elevation angle	 Same as transmit antenna $0.0 \rightarrow 1.5$ dBi $20^0 \rightarrow 90^0$ elevation angle
EIRP	$1.5 \rightarrow 3.0$ dBW	N/A
G/T	N/A	$-25.0 \rightarrow -23.5$ dB/K
Modulation	CDMA/QPSK	CDMA/QPSK

Table 4.1 Odyssey Handset Summary From Ref. [22]

D. SUMMARY

Odyssey system is a mobile satellite communications system for the provision almost globally of high quality voice services that will serve the increasing number of "roamers" and for low-cost data services. A constellation of twelve medium earth orbit (MEO) "bent-pipe" satellites can establish communication between mobile and fixed users or between pairs of mobile users. A mobile user using his dual-mode handset can communicate, in the absence of a terrestrial cellular system, with an Odyssey satellite (with L/S-band links) and through Odyssey earth stations with another mobile user or through gateways to another PSTN user.

V. GLOBALSTAR

A. INTRODUCTION

Globalstar is a low earth orbit (LEO) satellite-based digital telecommunications system that will offer wireless telephony and other telecommunications services worldwide beginning in 1998. Globalstar will provide low-cost, high quality telephony, data transmission, paging, facsimile, and position location to areas currently underserved or unserved by existing wireline and cellular telecommunications systems.

With a constellation of 48 satellites at an altitude of 1414 km any mobile user can establish communication either with another mobile user (who is located between 74^0 North and South latitude) or with a fixed user (by using earth stations and gateways to the public switched telephone network, PSTN).

B. MARKETS AND PROPOSED SERVICES

Globalstar will operate on a non-common carrier basis. It will own and operate the satellite links of the network. It will sell its satellite communications capacity, either in bulk or on demand, to communications carriers, including cellular telephone providers as well as other carriers and entities.

Globalstar provides mobile RDSS, voice, and data services in conjunction with terrestrial cellular telephone service providers and/or other communications service providers.

Globalstar provides RDSS on a stand-alone basis or in combination with messaging and voice communication services. By subscribing to these services in various combinations, the user can meet his location determination and communications needs at costs equal to or lower than those of comparable terrestrial facilities. Applications for this service include, for example, location of fleet vehicles, tracking of military movements, medical emergency, location of stolen vehicles, and recreational activities.

Globalstar provides voice and data services to many groups of users (fixed and mobile). These groups of users may include, for example, governmental agencies, commercial users, managers of fleets of air, land and water vehicles, persons traveling on business or pleasure, emergency service providers, transportation entities and others.

Government agencies will benefit from two-way voice communications and position location capabilities in the areas of disaster relief, law enforcement, air traffic control, resource management and weather reporting.

C. SYSTEM DESCRIPTION

The Globalstar system consists of three major segments; space segment, ground segment, and mobile user segment. Figure 5.1 shows an overview of the system.

1. Space Segment

a. Constellation

The space segment is composed of a constellation of 48 operational LEO satellites at an altitude of 1414 km and 8 in-orbit spares. This constellation provides 100

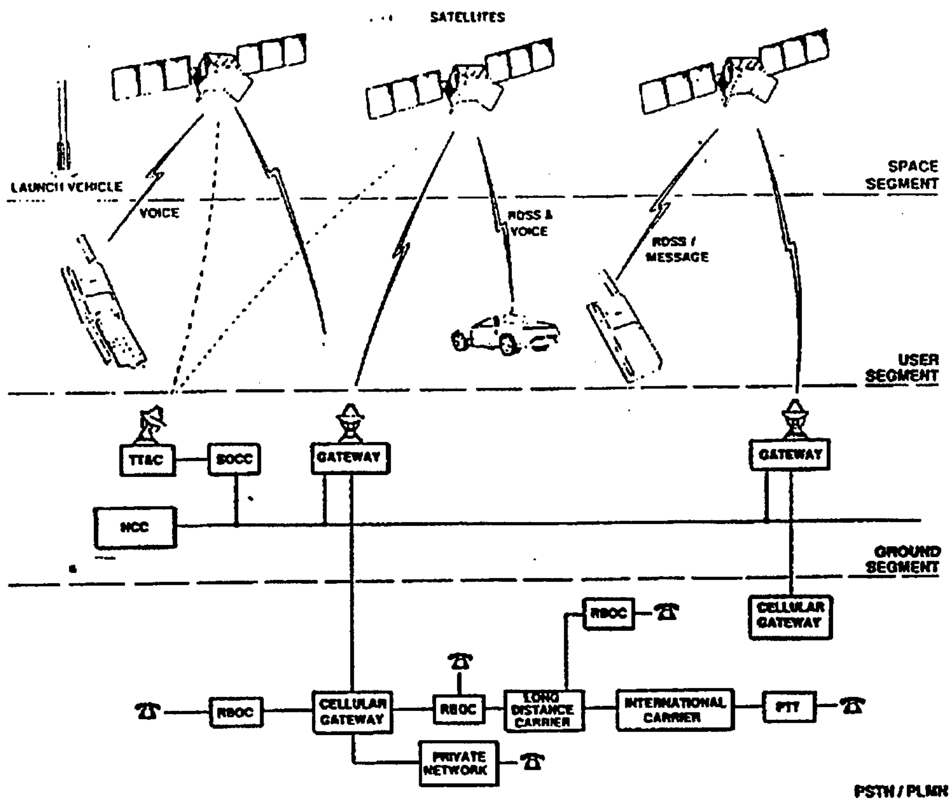


Figure 5.1 Overview of Globalstar From Ref. [23]

percent coverage among 74^0 North and South latitude for 24 hours a day at a 5^0 elevation angle. There are eight circular orbital planes with 52^0 inclination. The separation between planes is 45^0. Each plane has six satellites, which are equally phased within the orbital plane (60^0 intervals). Each orbital plane has a 7.5^0 phase shift to the satellite in the adjacent orbital plane. The orbital period is 114 minutes. Over the United States, coverage is such that there are three or more satellites providing services to the public, for 100 percent of the time.

b. *Frequency Plan*

Loral/Qualcomm Partnership (LQP) constructs its MSS system with the capability to operate over the 1610-1626.5 MHz uplink band (L-band) and the 2483.5-2500 MHz downlink band (S-band). Globalstar is a CDMA system so it possibly will operate its uplinks within the 1610-1621.35 MHz segment in order to conform to the band-sharing plan proposed by FCC.

Globalstar will operate its feeder links in C-band. Its feeder uplink in the 5025-5225 MHz band and its feeder downlink in the 6875-7075 MHz band (see Figure 5.2). In the user link bands, the spectrum is divided into 1.23 MHz sub-bands (13 sub-bands in 16.5 MHz bandwidth). Within each 1.23 MHz sub-band, CDMA is used for multiple access purposes.

c. *Frequency Reuse/Cell Management*

Each satellite has sixteen spot beams which form "coverage cells" on the surface of the earth for links between the mobile users and the satellites (see Figure 5.3). Spread spectrum CDMA techniques, combined with multiple spot beam antennas, permit the spectrum to be reused many times over United States and world, to achieve high spectral utilization efficiency. With 48 satellites and 16 beams, the spectrum can be reused 768 times over its global coverage.

The sixteen spot beams of the satellite generate elliptical coverage cells on the surface of the earth. The major axis of these elliptical coverage cells are aligned with the velocity vector of the satellite movement, so that the time a user stays within the same satellite cell is increased and the number of call hand-off operations among the satellite

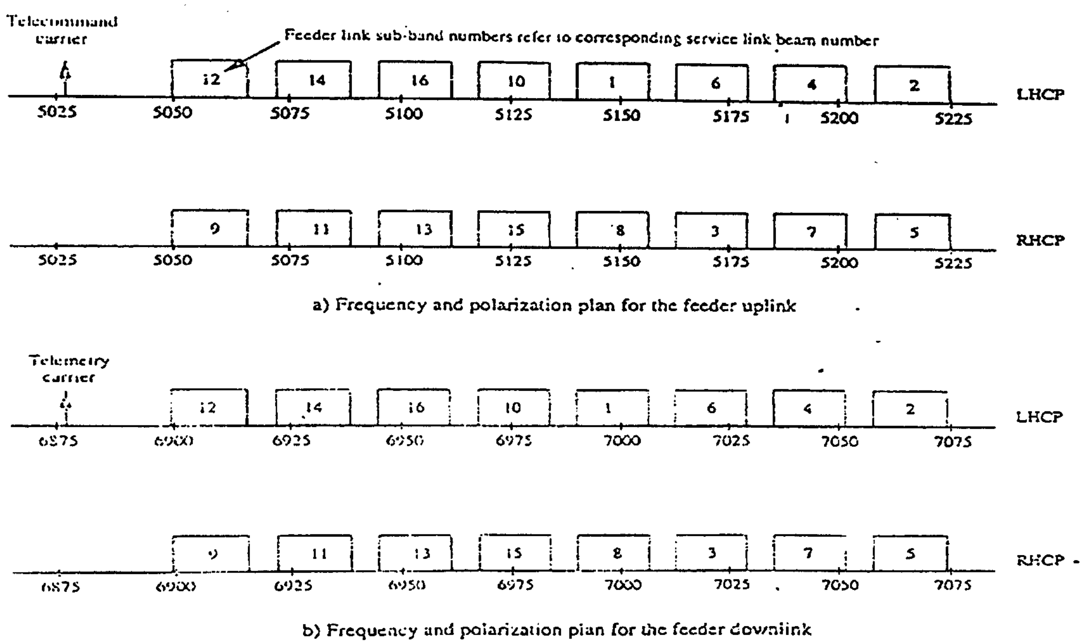


Figure 5.2 Feeder Link Frequency Plan From Ref. [23]

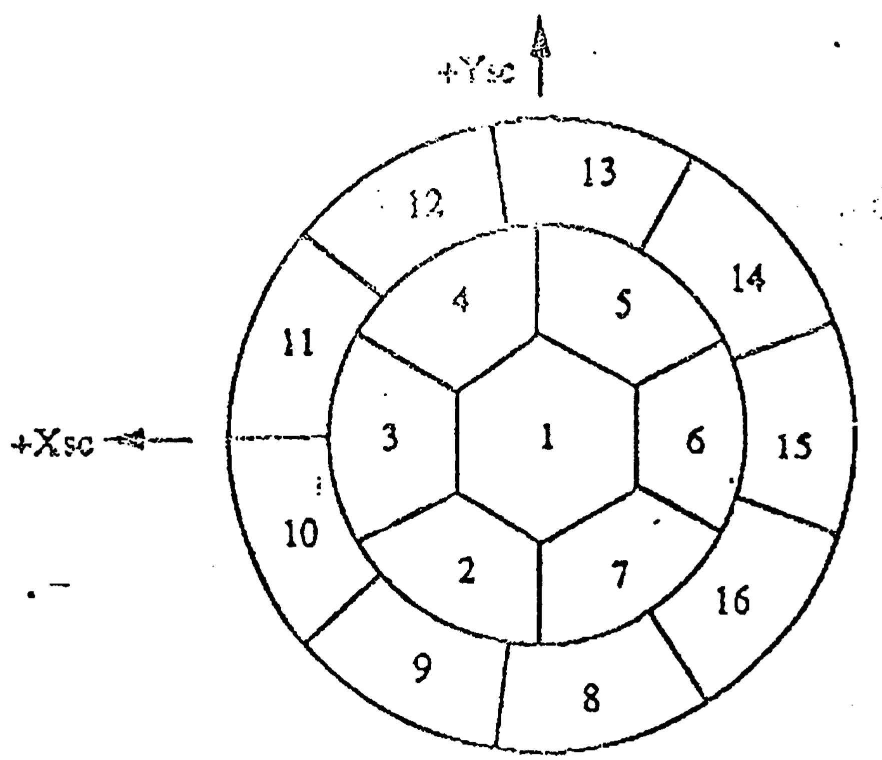


Figure 5.3 Individual Service Beam Coverage Pattern From Ref. [23]

beam cells is reduced. The Globalstar satellites' spot beam antennas are also designed to compensate for the difference in the satellite-to-user link losses between the "near" and the "far" users, so that the power flux density of the "far' users is about the same as the "near" users (i.e., an isoflux design). This antenna will reduce the near-far problem experienced by many cellular type systems. Also, with this type of antenna, harmful interference into the system can be reduced and the capacity of the system can be increased.

d. System Capacity

The CDMA techniques used by Globalstar result in a very efficient use of spectrum. The system can achieve over 2,800 full duplex voice channels capacity through a single satellite. Of course, a mobile user will be covered by two or more satellites. Therefore, neighboring satellites can coordinate to provide about 5,000 simultaneous voice channels. Over 134,400 full duplex voice channels can be achieved for the global coverage.

Digital data services will be accommodated by using a variable data rate from 2.4 Kbps up to 9.6 Kbps. The quality of services will be high by using error correction techniques.

e. Transmission Characteristics

Globalstar will provide RDSS, voice and data services at low cost with "bent-pipe" type transponders. Voice service is to be provided at 4800 bps and data services at speeds of 2400, 4800, and 9600 bps. The services provided will be of high

quality by using error correction code. At the forward link the code will be convolutional with r=1/2 and k=9 while at the reverse link will be also convolutional with r=1/3 and k=9.

Spread spectrum CDMA has been chosen for multiple access and QPSK is the basic signal structure used for waveform modulation.

The polarization is LHC (Left-Hand Circular) on all service beams and both RHC (Right-Hand Circular) and LHC on feeder beams.

2. Ground Segment

The Globalstar ground segment consists of: (1) gateways, (2) the network control center, and (3) the telemetry, tracking and command stations and satellite operation control centers.

a. Gateways

Each satellite communicates with the mobile user via the satellite-user links and with gateway stations directly via the feeder links. Figure 5.4 illustrates the block diagram of a gateway terminal. The RDSS functions are performed at the gateway stations or at the user terminal, while voice/data communications are routed through the gateway stations. Each gateway station initially will communicate with three satellites simultaneously. Gateways handle the interface between the Globalstar network and the PSTN. There are many gateways (six coordination gateways and ideally a gateway for each cellular telephone operator) distributed throughout the United States. Most of these gateway stations are connected directly to the mobile switch centers of the land mobile

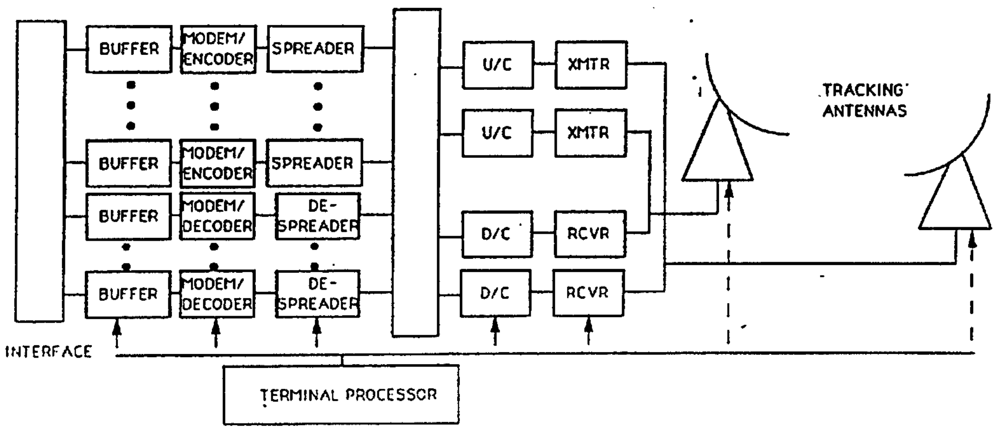


Figure 5.4 Block Diagram of a Gateway Terminal From Ref. [23]

network. For global service, gateway stations and other NCC's will be installed all over the world by PTT's or communications carriers of different countries to provide interconnection to the local PSTN.

b. Network Control Center

The network control center (NCC) provides the capability to manage the Globalstar communications services. Its functions include; registration, verification, billing, network database distribution, network resources (channels, bandwidth, satellites, etc.) allocation, and other network management functions. Other system services, such as message service, may also provided through NCC. Initially, there will be one NCC for cellular systems in the United States. NCC's can be added later, if needed.

c. Constellation Control

The constellation control operation includes the TT&C stations and the satellite operation control center (SOCC). The TT&C stations monitor each satellite's

operation via the telemetry of the satellites and send commands to the satellite to control its on-orbit performance. The TT&C stations also perform tracking and ranging functions for the orbiting satellites. The ephemeris of the satellites are transmitted to the SOCC. The SOCC processes the satellite orbit information for various network functions, e.g., acquisition and synchronization, hand-off between satellites and hand-off between beams. The processed information and databases are distributed to Globalstar gateways for tracking and other purposes. The SOCC also plans and executes orbit station-keeping for the satellites, so that all satellites are maintained in the appropriate orbits.

The constellation control operation (CCO) supports the launch operation and in-orbit-test operation. When a satellite reaches the end of its life, the CCO removes the satellite from orbit and moves spare orbiting spacecraft to replace the old spacecraft.

Initially, two TT&C stations and one SOCC will be installed in the US. Additional TT&C's and SOCC's will be implemented for the global network.

3. User Segment

The user segment consists of hand-held, mobile and fixed terminals. Hand-held and mobile terminals may be single or dual mode (i.e. to operate as a terrestrial cellular terminal and as a Globalstar terminal). Fixed terminals would be used solely for Globalstar services. The hand-held unit is similar to those for terrestrial cellular networks in size, weight, and power. The mobile unit is similar to a car-radio.

Globalstar is a fully digital system which uses a variable rate voice encoding technique to provide high quality voice service. Bit rates range from 2.4 Kbps to 9.6 Kbps. The digital signal is spread over 1.25 MHz bandwidths in the L/S-bands using

Direct Sequence CDMA. The peak power of the user segment is 2W and the modulation technique is QPSK. Forward error correction techniques are also used.

D. SUMMARY

Globalstar system will provide voice, data, facsimile and RDSS services. It will use a network of 48 satellites in inclined orbits 1414 km above the earth to provide almost global coverage. Each satellite directs 16 beams to the earth to receive and send messages to hand-held units or to gateways. The system is intended to work with the existing public switched telephone network (PSTN). Calls are relayed through the satellite only when access cannot be made to the terrestrial network. The existing PSTN will be accessed via gateways and will be used for long-distance connections including transoceanic calls.

VI. COMPARISON

A. INTRODUCTION

In previous chapters a detailed summary for each of four important satellite-based commercial personal communications systems (PCS) was given. Three of them (Iridium, Globalstar, and Teledesic) are LEO satellite systems and one (Odyssey) is MEO satellite system. Also, three of them are narrowband systems (Iridium, Globalstar, and Odyssey) while Teledesic is a wideband one. In this chapter a comparison of the four systems will be presented. First a summary of system parameters will be obtained. Then criteria for comparison are defined.

B. SYSTEM PARAMETERS SUMMARY

Table 6.1 lists the system parameters of the four systems described in details in previous chapter. There are a few papers in the literature that compare Iridium, Globalstar, and Odyssey using as criteria, technical, technology, business, and regulatory aspects. Garry M. Comparetto compares these systems and concludes: [Ref. 3]

"It is clear that Iridium will be the most challenging to deploy due to the inclusion of on-board processing techniques within the satellite communications payload together with a high data rate satellite crosslink capacity. Furthermore, The FDMA/TDMA multiple access scheme proposed for Iridium presents a number of complex issues

	Iridium	Teledesic	Odyssey	Globalstar
Orbit Class	LEO	LEO	MEO	LEO
Altitude (km)	780	700	10355	1414
Number of Satellites	66	840	12	48
Number of Planes	6	21	3	8
Period (minutes)	100	98.8	360	114
Inclination (Degrees)	86.4	98.16	50	52
Elevation (Degrees)	8.2	40	20	10
Proposed Services	RDSS/Voice/Data	Multimedia	RDSS/Voice/Data	RDSS/Voice/Data
Multiple Access	TDMA	TDMA/SDMA	CDMA	CDMA
Modulation	QPSK	QPSK	QPSK	QPSK
Voice (Kbps)	4.8	16	4.8	2.4/4.8/9.6
Voice Quality	1,00E-02	1,00E-09	1,00E-03	1,00E-03
Data (Kbps)	2.4	16-2048	2.4	2.4-9.6
Data Quality	1,00E-05	1,00E-09	1,00E-05	1,00E-05
Voice Channels/Satellite	3840	20000	3000	2800
Beams per Satellite	48	64	61	48
Satellite Antenna	Fixed	Steerable	Steerable	Fixed
Cells	Moving	Earth-Fixed	Earth-Fixed	Moving
Coverage	Global	72 N-72S	70N-55S	74N-74S
User Uplink (MHz)	L-band	Ka-band	L-band	L-band
User Downlink (MHz)	L-band	Ka-band	S-band	S-band
Feeder Uplink (GHz)	Ka-band	Ka-band	Ka-band	C-band
Feeder Downlink (GHz)	Ka-band	Ka-band	Ka-band	C-band
On-board Processing	Yes	Yes	No	No
Intersatellite Links	Yes	Yes	No	No
Handheld Terminals	Yes	No	Yes	Yes
Dual-Mode Terminals	Yes	No	Yes	Yes
Satellite Lifetime (yrs.)	5	10	15	7.5
System Cost (billion $)	3.4	9	1.3	1.8
Handset Cost (US $)	2000-3000		500	750
Charges ($ per minute)	3		0.65	0.30
FCC Approved	Yes	No	Yes	Yes
Operation Scheduled	1998	2001	1998	1998

Table 6.1 System Parameters Summary

involving cell utilization, cell frequency management, and time synchronization. The Globalstar system seems to be well postured, from a technical standpoint, due to the in-house experience of QUALCOMM in the area of CDMA/cellular applications. However, Odyssey may be in the best position to achieve its stated cost and performance objectives

due to the small number of satellites required in the design along with the use of a proven communications bus onboard the satellite."

Klaus G. Johannsen also compares Iridium, Globalstar, and Odyssey among other commercial satellite based PCS and concludes that Odyssey may be the best mobile satellite system [Ref. 5]. Of course, in our case the criteria will be different from those of the two above authors in order to compare these systems for military applications.

C. CRITERIA

The objective of this thesis is to find out if these commercial PCS satellite systems can be used for DoD communications. Therefore, these systems will be compared using the following criteria; antijam protection, security, low probability of interception/low probability of detection (LPI/LPD), interoperability, grade of service, signal quality, systems availability, cost, coverage, mobility, flexibility, control, and capacity.

1. Antijam Protection

For tactical and strategic military satellite communications (MILSATCOM), antijam protection is of major concern. In a satellite link either the uplink or the downlink may be targeted by an intentional jammer. The vulnerable element has traditionally been the uplink since a successful jamming attack on the uplink can disrupt the entire user community utilizing the transponder(s). Generally ECCM techniques can be employed on either the spacecraft or the ground and should be considered as part of the total link protection. These techniques comprise: spread spectrum, error control coding, adaptive

nulling or multi-beam antennas, spacecraft autonomy, intersatellite links. It is highly likely that one or more of these methods will be employed in military satellite communications depending on the required grade of service, the priority links, availability and the perceived threat. [Ref.1]

The proposed commercial satellite PCS systems are not designed to sustain intentional jamming. Thus, during a crisis, electronic jamming could severely degrade the performance of these systems and limit system capacity to support a high number of requests. However, two of the above four systems offer some degree of antijam protection.

Globalstar and Odyssey plan to use code division multiple access (CDMA) which by its nature is a spread spectrum technique. Iridium and Teledesic plan to use intersatellite links. These two systems have forward error correction coding and Viterbi decoding which enhance the antijam capability.

2. Security

This issue is of primary concern for all PCS users and is expected to be resolved by the PCS industry. The "masquerade attack" is an example of one threat, where an intruder pretends to be an authorized user to gain access to services for which his/her victim then pays. In DoD applications, the weakness to attack could severely damage the usefulness of PCS. A cost-effective, time-efficient solution must be developed to improve access security and information protection. An example to provide secure network access is by mutual authentication, as opposed to a simple personal identification number (PIN). Once the identity of the user has been firmly established, standard techniques can be used

to protect user information. An example is to use an enhanced STU-III style encryption into mobile terminal handset. Current versions of STU-III including the planned digital one are not applicable to satellite PCS applications from a physical protection standpoint.

Protecting tactical data and messaging is equally important. An example could be the implementation of National Security Agency approved cryptographic algorithm called MISSI, which is a low cost method to protect unclassified but sensitive messaging. [Ref. 10]

3. LPI/LPD

For satellite personal communication systems, allowing system access anywhere in the world is important and useful for DoD. This feature however results in mobile user vulnerability since they can be located and their movement can be tracked by intercepting their transmit signals at two or more sites [Ref. 10]. Therefore, low probability of interception and detection is required for mobile satellite systems.

LPI/LPD capability of a communications system relates to its coverage as well as the waveform used. CDMA waveforms provide limited signal discrimination and LPI/LPD. [Ref. 4]

4. Interoperability

DoD wants to achieve interoperability among tactical users and seamless communications support under flexible force deployment options in any environment including maritime, air and ground. Up to now, fierce competition in the PCS business has kept the satellite systems developers working indepedently in order to protect their

proprietary information. For example, different voice coding algorithms are being pursued. An effect could be that two users using different systems might not be able to communicate with one another. The other differences between the planned satellite PCS systems include different frequency plans, multiple access schemes, and transponded satellites versus on board processed satellites. The satellite systems planning to use the CDMA waveform design such as Globalstar and Odyssey could conceivably interoperate over each other satellite. However, different proprietary technologies in these PCS systems will create more costly and complex solutions for interoperability.

Furthermore, since a hybrid PCS network is envisioned, a common handset allowing accesses to different systems will be desired offering convenience and improving systems interoperation. Otherwise, a user must be equipped with many terminals to use different satellite PCS systems. DoD wants an approach such that a multi-mode terminal commonality is feasible without excessive costs. [Ref. 10]

5. Grade of Service

Tactical commanders require assured access to satellite systems 24 hours a day throughout the world. During a crisis, tactical commanders may keep getting busy signals due to demands for service exceeding capacity. Thus, military satellite PCS users may have to be provided with a special signaling channel in order to achieve immediate access and high priority service. None of the systems considered previously has any kind of this capability. [Ref. 10]

6. Systems Availability

Most of the systems (Globalstar, Iridium, Odyssey) are planned to be available by 1998. However, while the technical feasibility of the systems seems to be secure, their economic viability is somewhat more questionable. Yet, Iridium still needs about $1.8 billion of the $3.4 billion estimated for its network. Globalstar have raised much less amounts than needed. Teledesic ($9 billion estimated cost) has not yet be granted a license from Federal Communications Commission (FCC). Because of these uncertainties, maybe it is better for DoD to wait until it is learned which systems will come to reality.

In addition, there are some other issues that could delay the availability of the proposed systems. They include worldwide frequency allocation and management, inter-system interference, and gateway complexity.

7. Signal Quality

All PCS providers plan to offer voice, data, facsimile and other services such as messaging, paging, and position location service. Teledesic plans to offer and multimedia service. The bit error rate (BER) for voice is 10^{-2} for Iridium and 10^{-3} for the others. The bit error rate for data is 10^{-9} for Teledesic and 10^{-5} for the others. The typical supportable data rates are 4.8 Kbps for voice and between 1.2 Kbps and 9.6 Kbps for data. Teledesic supports more than 2 million simultaneous full-duplex 16 Kbps basic channels, up to 2.048 Mbps "on demand" channel rates, and for special applications up to 1.24416 Gbps.

8. Cost

Although cost is not an explicit criteria, let's have an idea about prices for the mobile terminals and cost of service. The estimated initial prices for the mobile terminals vary considerably with Odyssey projected selling for under $500, followed by Globalstar at $750, and Iridium at $2000 to $3000. The mobile terminal for Teledesic is briefcase sized and there is no estimation for its price. On the other hand, the projected cost of service ranges from $0.30 per minute to over $3 a minute. LQP plans to charge $0.30 per minute for the Globalstar service plus $0.10 per minute for tail charges to connect to local or long-distance services. In addition, a monthly service charge of $8 to $10 is anticipated based on current cellular experience. The retail price of Odyssey service is estimated at $0.65 per minute plus about $0.10 for tail charges and a monthly service of about $24. Motorola plans to charge $3 per minute plus tail charges. Teledesic plans to charge subscribers to those charged for similar services provided by terrestrial systems.

9. Coverage

Global changes have resulted in a fundamental change to U.S. National Military Strategy. This strategy will increasingly rely on the capability to project combat power with joint military and/or government organizations. The Armed Forces must be prepared to support joint operations ranging from peacetime engagements to war. These operations could included nation assistance, civil-military operations, regional conflicts, attacks and raids, and declared wars. Also, satellites are the optimum choice (not to say the only one) to communicate with warships operating anywhere on the globe. Therefore, satellite

systems must cover the whole earth's surface 100% of the time, including polar (north and south) regions. [Ref. 7]

Iridium plans to provide global coverage, Teledesic between 72^0 north and south latitude, Globalstar between 74^0 north and south latitude, and Odyssey between 70^0 north and 55^0 south latitude.

10. Mobility

At the present, communicating over an existing commercial satellite would require the use of terminals that are not conveniently carried from location to location as many mobile users would want. Planned satellite based PCS systems on the other hand would offer seamless communication mobility for users with conveniently carried transceivers [Ref. 10]. Today considerations for about the deployment of a military force, emphasize on its mobility. As forces begin to move to their objectives, the ability to communicate with them during the move, is a challenging issue.

The concept of a digital connection to anywhere at anytime is perfectly adaptable to the needs of a mobile military force. Planned PCS systems using LEO/MEO satellite constellations make this concept a reality and will support the military needs of "Communications on the Move" .[Ref. 11]

Iridium, Globalstar, and Odyssey with their hand-held units will support enough mobile military forces. Teledesic on the other hand will also offer mobile satellite services (MSS) to them, but its primary plan is to offer fixed satellite services (FSS).

11. Flexibility

DoD requires satellite-based systems to be flexible in two ways: to be compatible with other satellite systems and to be compatible to many digital PSTNs and public land mobile networks (PLMNs). All four systems provide the capability to be connected to PLMN with dual mode terminals and to PSTN with gateways.

Gateways also must be flexible and transportable. Globalstar's feeder links are in C-band allowing to support a tactical system with inter-theater connectivity. Iridium and Odyssey on the other hand, use Ka-band feeder links that require use of multiple, interconnected gateways spaced at least 10 km apart in order to overcome potential loss of availability due to rain attenuation.[Ref. 4]

12. Control

All four systems are designed and will be operated by U.S. companies (Motorola, Teledesic Corp., Loral/Qualcomm, and TRW). However, it is risky to say definately that DoD will have complete control on these systems whenever it is needed.

13. Capacity

Last but the most important, the issue of capacity. Teledesic by its proposed mission has the largest capacity of 100,000 full-duplex 16 Kbps connections per satellite. Iridium is power-limited at 1,100 circuits per satellite. Odyssey and Globalstar have capacities of 3,000 and 2,800 full-duplex voice channels respectively through a single satellite. These numbers can be increased up to 6,000 and 5,000 respectively, whenever users are covered by two or more satellites.

D. CONCLUSIONS

Without question there is a role for commercial mobile satellite communications in support of world-wide military operations. An effort by a Loral team showed that approximately 1/3 of the MSS DoD traffic is general purpose traffic which does not need to meet the full spectrum of MILSATCOM requirements. The remaining 2/3 traffic is core traffic and has more stringest requirements. Commercial MSS systems can meet approximately 45% of the DoD MSS requirements, if the 11% of the core requirements are added to the general purpose traffic. [Ref. 4]

Commercial satellite PCS systems have the potential to satisfy military mobile communications needs that are currently satisfied by UHF military communications satellites. Transferring military UHF traffic to commercial satellite PCS systems frees up capacity on government systems that would be used to support additional mobile tactical users. Another benefit is possible cost reduction derived from use of commercial-off-the-self (COTS) products and from competitive service charges resulting from anticipated fierce competition in the PCS market. An example is the availability of commercial maintenance support and equipment warranties, which means that DoD does not have to establish unique and more costly operational and maintenance. Another benefit is military mobile users are provided with state-of-the-art commercial technology. [Ref. 10]

Conclusions are summarized as follows:

1. Commercial LEO/MEO satellite systems have the potential to provide communications support for DoD's less critical needs which include administration, logistics, and other support functions.

2. None of the commercial systems that were studied meets all the DoD requirements.

3. An architecture consisting of Odyssey and Globalstar meets the most of the criteria and government requirements for MSS services.

4. Teledesic is the only system to provide higher data rates (>64 Kbps) to mobile users operating directly with FSS systems.

5. Iridium is the only system to provide polar (north and south) coverage.

VII. MILITARY APPLICATIONS

A. INTRODUCTION

In this chapter, we investigate which are the potential military applications of the commercial satellite systems described in previous chapters. A historical overview of military communications by satellites and a brief description of current systems are provided. Then, a brief discussion of the areas where the LEOS systems can be used is provided. Finally, the possibility to provide satellite communications to MAGTF (Marine Air-Ground Task Force) is investigated.

B. HISTORICAL OVERVIEW OF MILSATCOM SYSTEMS

It all started in October 1957, when the Soviets launched Sputnik, the first artificial satellite to be sent into space. Sputnik could be considered as an orbiting radio transmitter rather than a communications satellite. It was soon recognized that human-made artificial satellites offered a novel transmission medium with unique features for both commercial and military communications. Only a few satellites could provide worldwide coverage with distance-insensitive cost, flexible interconnectivity among dispersed users over a wide geographic area, large transmission bandwidths to support high data rates, rapid extension of communications into new or isolated areas, and beyond line-of-sight service to mobile platforms such as aircraft, ships and submarines. In many military scenarios, satellites provide a more reliable alternative to conventional

microwave, troposcatter, and high frequency radio systems; in particular for accomplishing such important functions as broadcast, report-back, and conferencing among dispersed users.

As launch vehicle capability increases, the first geostationary satellite (SYNCOM III) was launched in August 1964 implementing Arthur Clarke's idea of geostationary satellites as communications relay. In April 1965 the first commercial communications satellite (INTELSAT I or "Early Bird") was launched with a capacity of 240 two-way transatlantic voice circuits.

The first U.S. military communications satellites, the DSCS I, were launched in June 1966. A total number of 26 satellites, were launched in four groups by TITAN 3C launch vehicles to near equatorial, 18,300 statute miles orbits. These satellites drifted from west to east at a rate of up to 30^0 per day for a lifetime of six years. This initial experiment was followed in February 1969 with the more ambitious tactical satellite (TACSAT) communications program. One satellite was placed in geostationary orbit and was used to evaluate mobile user needs in tactical situations.

In June 1970, residual DSCS I and TACSAT assets were available to U.S. Navy. This was followed by the approval of the Fleet Satellite Communications (FLTSATCOM) program by the Secretary of Defense in September 1971. TACSAT located in the Pacific area failed in December 1972. The Navy was faced with a five year period in the Pacific and a potential four year period in Atlantic during which no UHF SATCOM relay would be available. This was based on the assumption that the first FLTSATCOM satellite would be available by December 1978. To minimize this gap the Navy decided to lease UHF satellite communication services. A contract for a two ocean

coverage (Atlantic and Pacific) was signed and then modified to include coverage of the Indian Ocean.

DSCS I satellites were followed by DSCS II and III. The first two DSCS II were launched in November 1971. By September 1982, 16 phase II satellites had been launched, four were not placed in orbit due to launch vehicle failures and four are operational with varying degrees of availability. The DSCS III satellites are currently replace the DSCS II ones. [Ref. 2]

C. CURRENT MILSATCOM SYSTEMS

The DoD currently uses both military and commercial systems to meet its demand for satellite communications. Military systems operate in the UHF (240-400 MHz) and SHF (8/7 GHz) bands with a diverse mix of fixed, mobile, and transportable terminals. Additional communications are provided through leased circuits on commercial C (6/4 GHz) and K_u (14/11 GHz) band satellites.

1. Fleet Satellite Communications System (FLTSATCOM)

This UHF system consists of government-owned FLTSAT, and leased-service provided by contractor-owned LEASAT satellites. These geostationary satellites, provide communications to tactical/mobile users such as ships and submarines. They have multiple 25-KHz and 5-KHz channels, and one 500-KHz channel. The signal on the uplink is a pseudo-noise spread spectrum one at X-band. This signal is despread onboard the satellite and retransmitted on the downlink at UHF.

2. Airforce Satellite Communications Systems (AFSATCOM)

This system consists of a number of satellites in inclined elliptical orbits and shares FLTSAT with FLTSATCOM system. The system provides a global capability for dissemination of the emergency action messages to nuclear-capable forces, and associated report-back communications. Principal users of the AFSATCOM system are small ground-transportable and airborne terminals. Each satellite carries twelve 5-KHz narrowband channels which are frequency hopped on the uplink.

3. Defense Satellite Communications System (DSCS)

Principal users of the DSCS system are fixed and transportable terminals and a limited number of mobile terminals supporting naval and air operations. It is the DoD's primary system for long-haul high-volume trunk traffic. The DSCS II satellites are currently replaced by DSCS III ones. The frequency plan of DSCS II allows operation in four frequency bands within the allocated 500-MHz spectrum. The DSCS III is the first military satellite with antenna nulling capability and its anti-jam capability is increased over DSCS II.

4. The MILSTAR System

This new system, will use the 44 GHz band on the uplink and 20 GHz on the downlink. The space segment will consist of a number of satellites in geostationary and inclined circular orbits for global coverage. Each Milstar satellite will incorporate onboard processing for enhanced anti-jam, multiple uplink and downlink beams to cover widely dispersed users, and nuclear hardening to achieve a high degree of survivability.

The signals will be frequency hopped over a wide bandwidth. The satellites will be crosslinked for world-wide connectivity, without the use of ground relays.

D. APPLICATIONS

The above described current military satellite communication systems offer high protection but have limited capacity. Today, there is a great demand for satellite communications to more users especially for mobile ones. The commercial satellite systems described in previous chapters have high capacity but low/medium protection. Therefore, they can be used for DoD's less critical communications needs such as administrative, logistics and other support functions. Transfering military traffic to these commercial PCS frees up capacity on military satellite systems to support more critical communication needs.

There are three categories of information services supported by current satellite systems; voice, data, and video services. These services are provided by three types of satellite communication systems; narrowband, wideband, and broadcast systems. Iridium, Odyssey, and Globalstar are narrowband systems and provide voice and low data rate services. Teledesic is a wideband system and provides data services (medium and high data rates), and video services. Of course, none of them is a broadcast system.

1. General Military Applications

Globalstar and Odyssey provide radiodetermination services. These services can be exploited by the military as follows: [Ref. 13]

1. Track position of units at command posts.

2. Track position of logistics throughout shipment with subscriber units integrated into the asset.

3. Remotely interrogate electronic tags and manifests.

4. Collect crucial environmental data located anywhere in the battlespace.

5. Monitor the status of remote sensors from the U.S. or field command posts.

6. Query the status of rapidly moving weapon systems.

7. Provide global search and rescue coverage for downed pilots.

2. U.S. Army Applications

Several changes in the global environment occurred within the past years that affected the operational requirements for communications on the battlefield. There is less concentrated focus on Eastern Europe and the former Soviet Union and more worldwide focus on new centers of power and regional conflicts. As a result, the following communications requirements are becoming increasingly important for GMF (Ground Mobile Forces): [Ref. 26]

1. Ability to rapidly deploy and scale the communications infrastructure to meet the requirements of the force structure as it changes.

2. Ability to deploy in a variety of environments.

3. Ability to provide communications on a dispersed battlefield.

4. Ability to provide communications support for rapidly moving forces, to include command and control.

5. Less reliance on terrestrial LOS systems, increased use of satellite ones.

Existing and planned U.S. Army's satellite and troposcatter communication systems require the user to stop, deploy, and point an antenna in order to establish a link. Other digital communication systems such as JTIDS (Joint Tactical Information Distribution System), SINCGARS (SINgle Channel Ground-Airborne Radio System) , and MSE (Mobile Subscriber Equipment) are limited by LOS and require relays. Therefore, Globalstar and Odyssey can be used by the U.S. Army to provide beyond the line of sight "communications on the move" for its units.

a. Application to MSE

The MSE (Mobile Subscriber Equipment) provides circuit-switched digital voice and data communications for a nominal U.S. Army Corps area and five associated divisions. It also provides packet-switced data communications service for LANs (Local Area Networks) and individual hosts. A block diagram of MSE is shown in Figure 7.1.

The fundamental principles of PCS (ubiquity, complete and continuous coverage) are critical for tactical communications. In a modern tactical environment users will require access to switched services in command posts, in vehicles, and in isolated forward areas. The authors in Ref. [26] suggest the adjusted MSE network shown in Figure 7.2, where the configuration consists of a command post, a wide area vehicular coverage, and an isolated forward area. Satellites are used to provide wireless access between base stations in forward areas and node centers. Also, there is no handoff capability in this proposed network. Handoff is not feasible for fast moving forces.

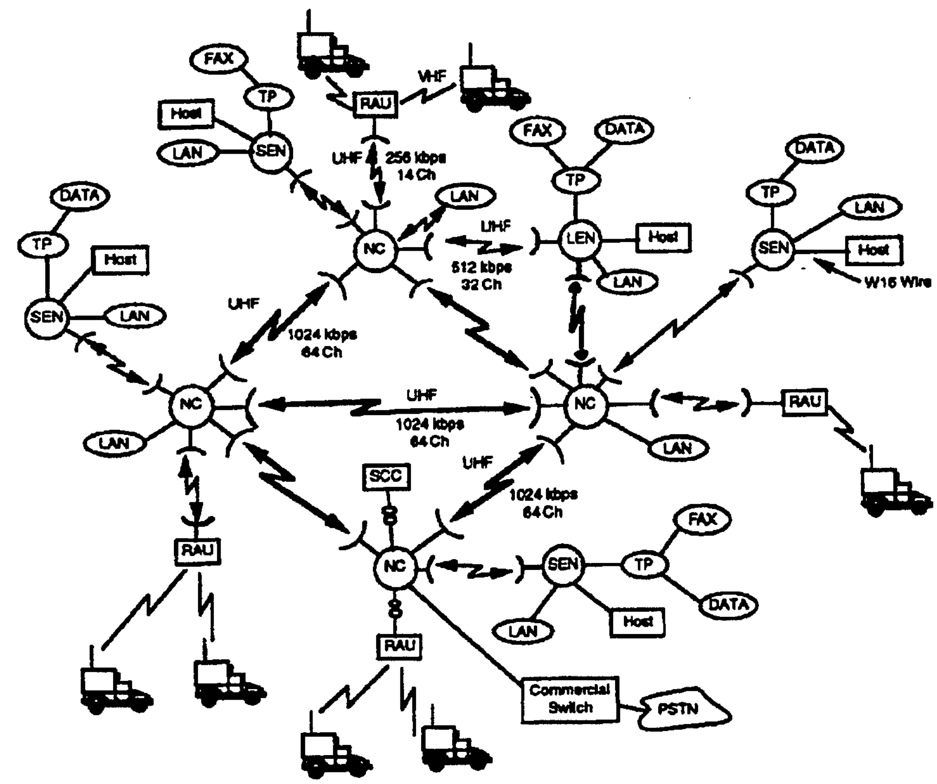


Figure 7.1 MSE System From Ref. [26]

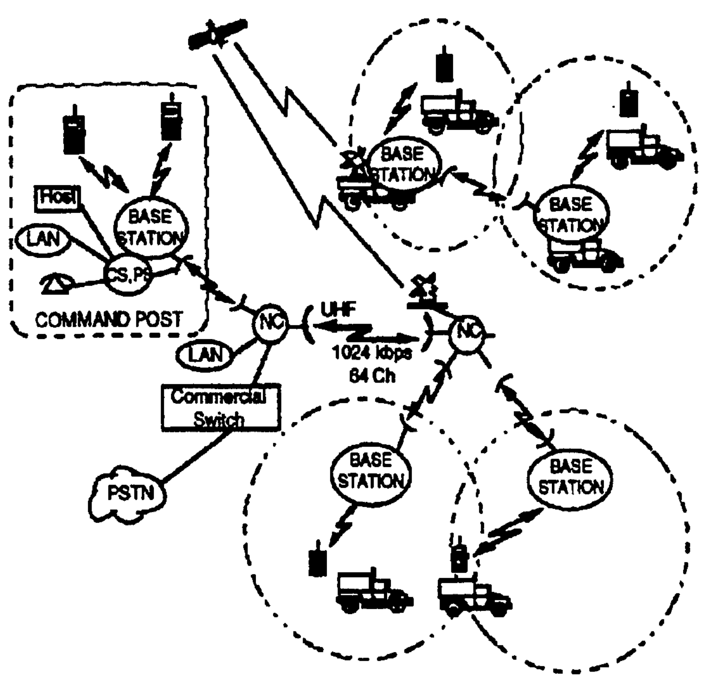


Figure 7.2 Adjusted MSE Network Model From Ref. [26]

Globalstar and Odyssey can be used to connect any mobile user of directly with the node centers, at least for logistics and other support functions. Also, can be used for LOS communication between node centers.

3. U.S. Navy Applications

Satellite communications is the essential link for Naval Forces. Naval Forces are mobile, worldwide dispersed, forces. There is no fiber/cable connectivity and non-satellite beyond line-of-sight communications systems by themselves will not satisfy the capacity and mobility requirements for Naval Forces.

Current satellite communication systems provide mainly communications between maneuver elements and command posts in CONUS. As information requirements are increased, more satellite capacity is needed to extend these services to lower echelons. Globalstar and Odyssey can be used to provide voice and low data rate services to ships, submarines, Marine Corps units.

E. APPLICATION TO MAGTF

1. Definitions

a. Marine Air-Ground Task Force

This is a task organization of marine forces (division, aircraft wing, and service support groups) under a single command and structure to accomplish a specific mission. The MAGTF components will normally include command, aviation combat, ground combat, and combat service support elements (including navy support elements). Three types of MAGTF which can be task organized are the marine expeditionary unit

(MEU), marine expeditionary brigade (MEB), and marine expeditionary force (MEF). The four elements of a MAGTF are:[Ref. 28]

(1) Command Element (CE). This is the MAGTF headquarters. The CE is a permanent organization composed of the commander, general or executive and special staff sections, headquarters section, and requisite communications and service support facilities. The CE provides command, control, and coordination essential for effective planning and execution of operations by the other three elements of MAGTF. There is only one CE in a MAGTF.

(2) Aviation Combat Element (ACE). The MAGTF element that is task organized to provide all or a portion of the functions of Marine Corps aviation in varying degrees based on the tactical situation and the MAGTF mission and size. These functions are air reconnaissance, antiair warfare, assault support, offensive air support, electronic warfare, and control of aircraft and missiles. The ACE is organized around an aviation headquarters and varies in size from a reinforced helicopter squadron to one or more marine aircraft wing(s). It includes those aviation command (including air control agencies), combat, combat support, and combat service support units required by the situation. Normally there is only one ACE in a MAGTF.

(3) Ground Combat Element (GCE). The MAGTF element that is task organized to conduct ground operations. The GCE is constructed around an infantry unit and varies in size from a reinforced infantry battalion to one or more reinforced marine division(s). The GCE also includes appropriate combat support and combat service support units. Normally, there is only one GCE in a MAGTF.

(4) Combat Service Support Element (CSSE). The MAGTF element that is task organized to provide the full range of combat service support necessary to accomplish the MAGTF mission. CSSE can provide supply, maintenance, transportation, deliberate engineer, health, postal, disbursing, enemy prisoner of war, automated information systems, exchange, utilities, legal, and graves registration services. The CSSE varies in size from a marine expeditionary unit service support group to a force service support group.

Marine expeditionary force (MEF) is the largest of the MAGTF and is normally built around a division/wing team while marine expeditionary unit (MEU) is the smallest of the MAGTF and is normally built around a battalion landing team, reinforced helicopter squadron, and logistic support unit.

b. Type of Services

Services can be distinguished in voice, data, and video services. Video services include videoteleconferencing (VTC), teletraining, telemedicine, broadcast TV, UAV imagery, movies, sports and recreational television. Data services include, tactical communications between maneuver elements and command facilities ashore and command and control (C2) for command elements (see Figure 7.3). Voice services include phones, voice mail, command nets, and coordination and reporting nets (C&R). [Ref. 27:p. 15-18]

c. Topology

A network topology can be distinguished in netted, hub & spoke, point to point, reportback, broadcast, and virtual. These topologies are illustrated in Figure 7.4.

d. Data Rate

The data rate can be high, medium, or low. Low data rate (LDR) is the rate less than 9.6 Kbps, high data rate (HDR) when is greater than 1.544 Mbps (T1), and medium data rate (MDR) when is between 9.6 Kbps and T1. MDR can divided furthermore in MDR1 (between 9.6 Kbps and 64 Kbps) and MDR2 (between 64 Kbps and 1.544 Mbps). [Ref. 27:p.109]

e. Protection

Protection can be categorized as high (operate through nuclear event, anti-scintillation, sanctuary jammer), medium (jammer with 200 nm of FEBA, transportable jammer), low (nuisance jammer, man-portable, neutral country jammer, US ownership and control of entire communications path), or none (no protection). [Ref. 27:p. 110]

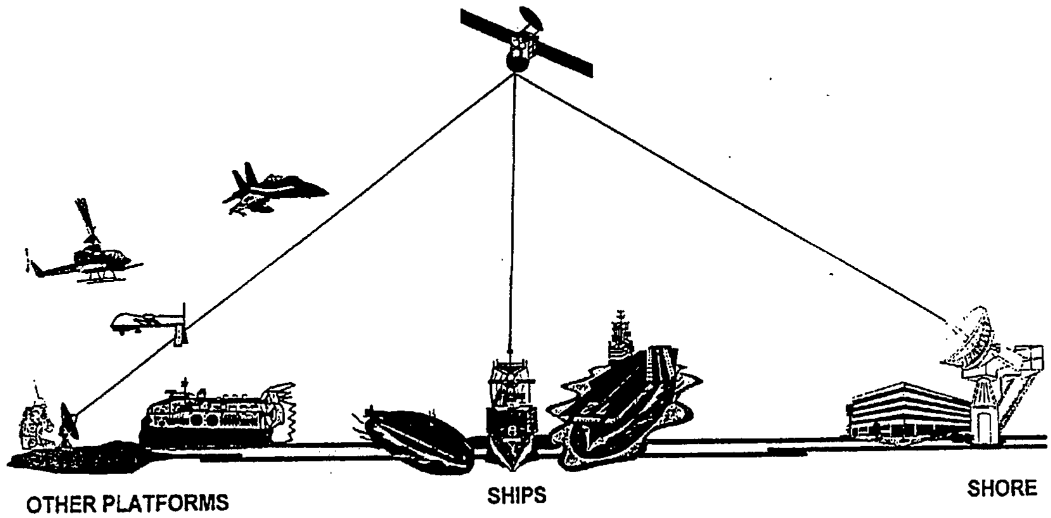


Figure 7.3 MAGTF Satellite Communications From Ref. [27]

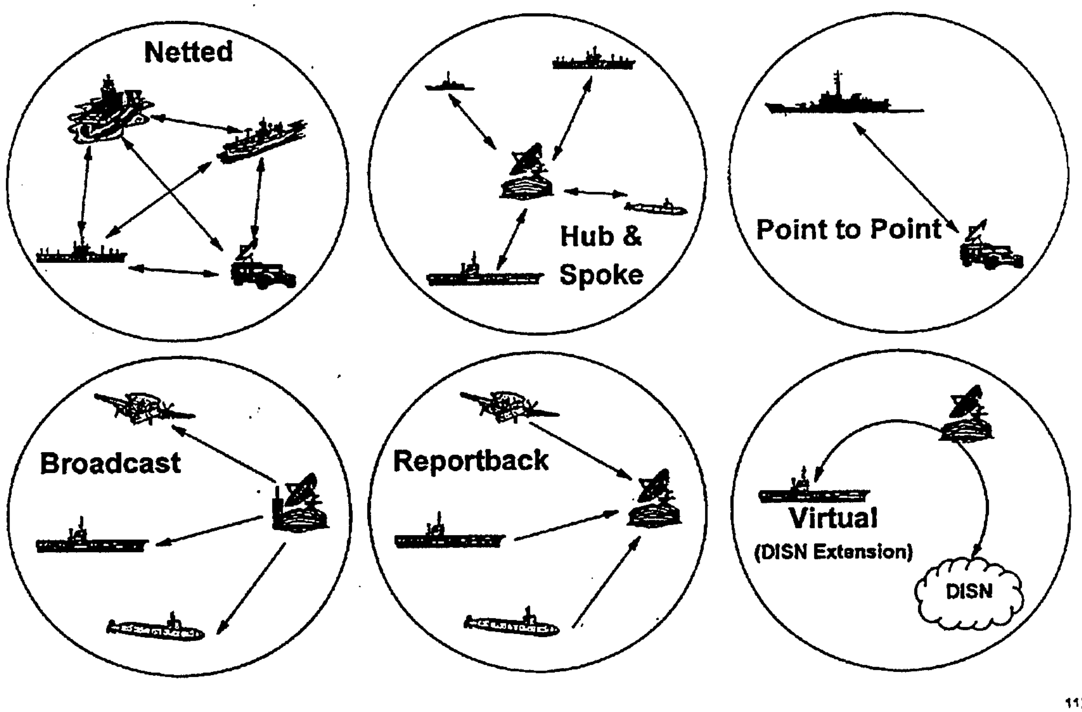


Figure 7.4 MAGTF Satellite Communications From Ref. [27]

2. MAGTF Circuit Requirements

The circuit requirements for MEF and MEU are shown in Figures 7.5, and 7.6. The circuit requirements for MEF are 250 voice, 300 data, and 10 video links. The circuits requirements for MEU are 30 voice, 70 data, and 5 video links.

3. Globalstar-Odyssey-Teledesic Capacity

Each Odyssey satellite has a capacity of 3,000 circuits and a "hot spot" beam 600 circuits. Each satellite provides high quality voice and data services. The basic digital data service for the handheld unit is 2400 bps (low data rate). The protection according to the criteria discussed above can be characterized as medium and of course Odyssey is not a broadcast system. With these assumptions Odyssey has the potential to provide all the voice services required for MAGTF (250 links for MEF, and 30 for MEU). Also can support part of the data services needed (see Tables 7.1, and 7.2).

Each Globalstar satellite has a capacity of 2,800 circuits. With the same assumptions as Odyssey, Globalstar can provide the same number of links as Odyssey.

Teledesic is the only proposed LEO wideband satellite system and can support MAGTF with video services (except broadcast services) and MDR and HDR data services (see Tables 7.1, and 7.2).

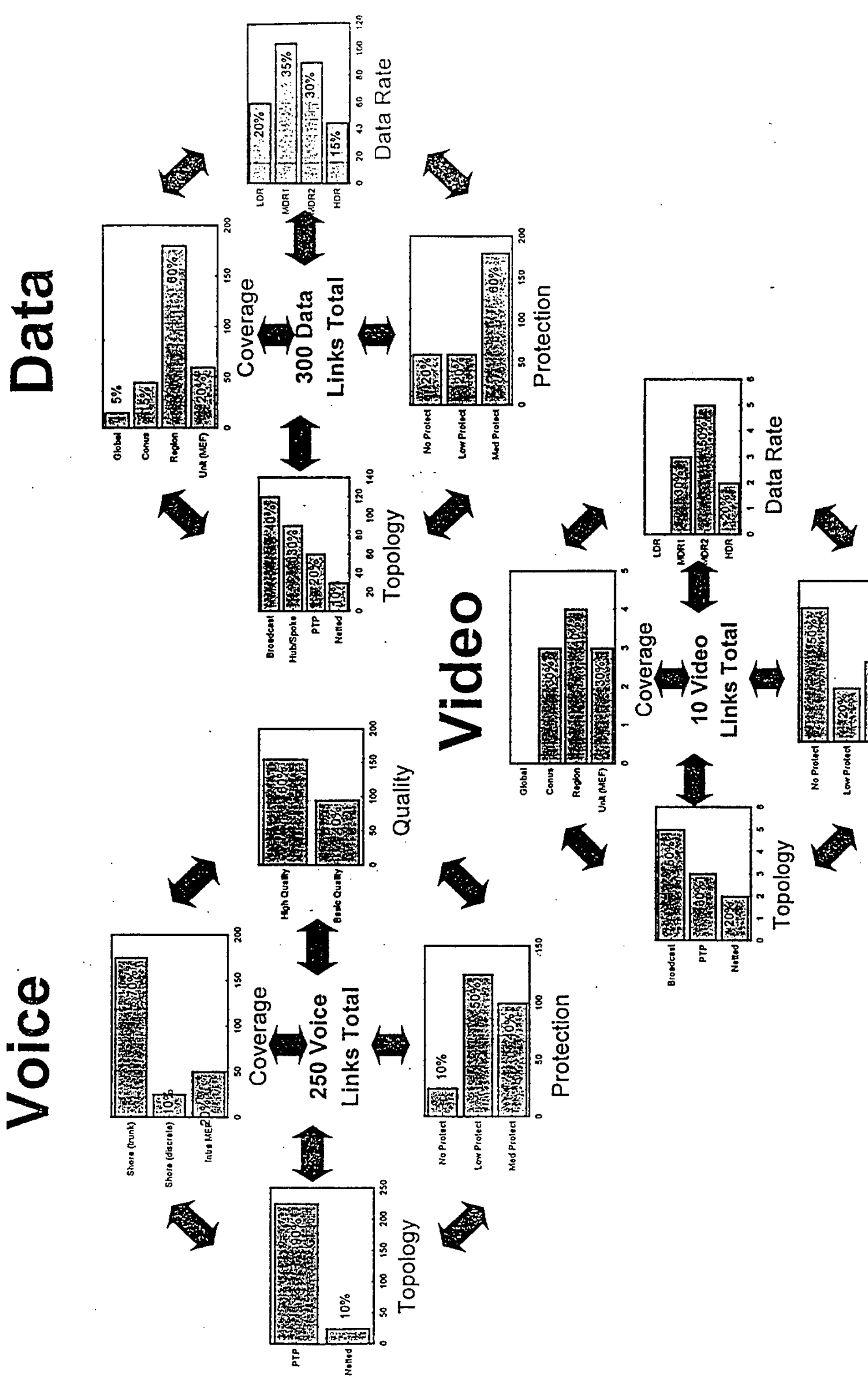


Figure 7.5 MEF Circuit Requirements From Ref. [27]

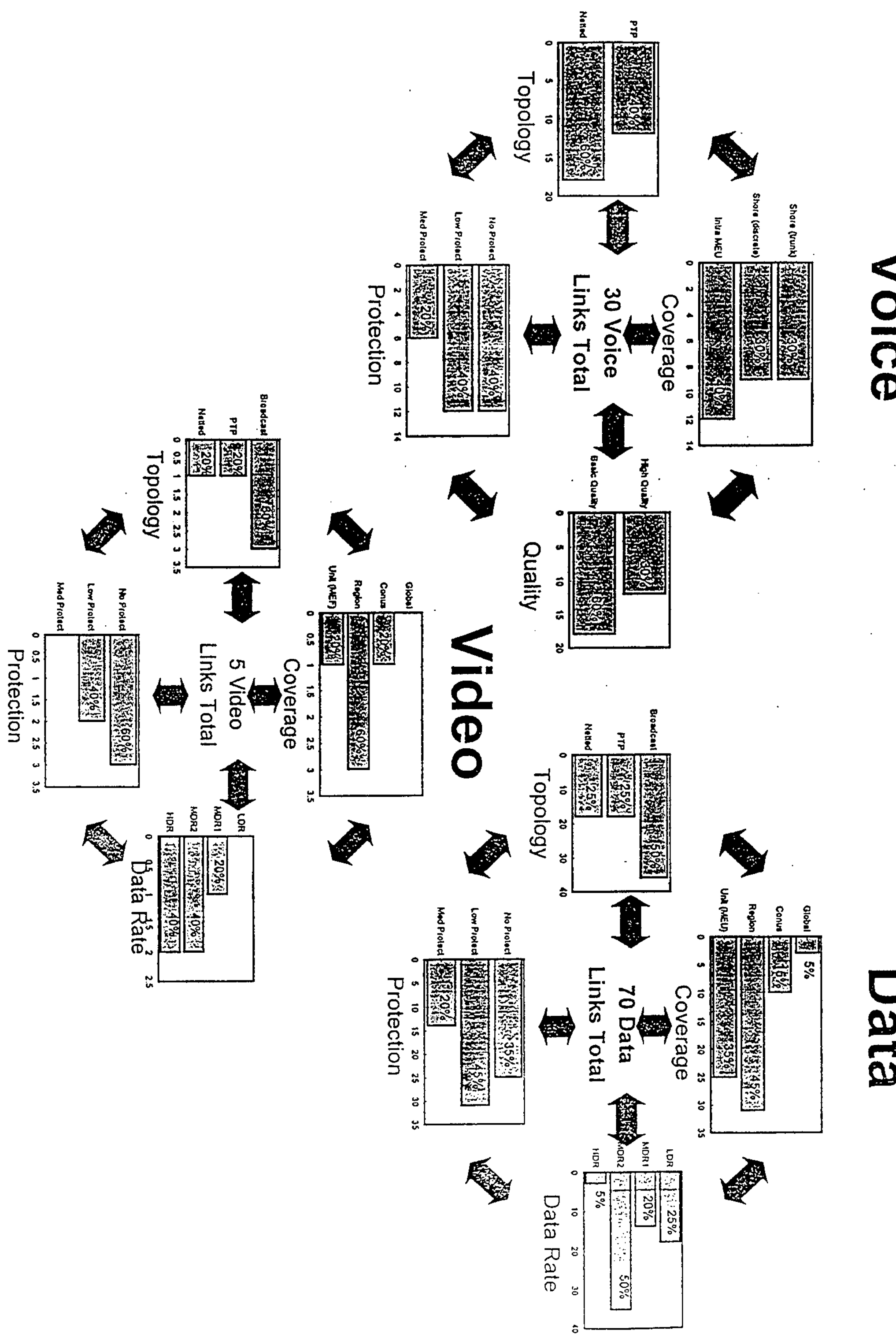


Figure 7.6 MEU Circuit Requirements From Ref. [27]

	VOICE				DATA				VIDEO			
	Quality	Coverage	Topology	Protection	Data Rate	Coverage	Topology	Protection	Data Rate	Coverage	Topology	Protection
Shore (Trunk)		175										
Shore (Discrete)		125										
Global						15						
CONUS						45				3		
Region						180				4		
Intra-Unit		50				60				3		
High	150											
Basic	100											
Broadcast							120				5	
Hub/Spoke							90					
PTP			225				60				3	
Netted			25				30				2	
No Protection				25				60				5
Low				125				60				2
Medium				100				180				3
High												
LDR					60							
MDR1					105				3			
MDR2					90				5			
HDR					45				2			
TOTAL	250	250	250	250	300	300	300	300	10	10	10	10
Odyssey	250	250	250	250	60	300	180	300				
Globalstar	250	250	250	250	60	300	180	300				
Teledesic					300	300	180	120	10	10	5	7
Military							120				5	3

Table 7.1 MEF Links Supported by Commercial LEO Satellite Systems

	VOICE				DATA				VIDEO			
	Quality	Coverage	Topology	Protection	Data Rate	Coverage	Topology	Protection	Data Rate	Coverage	Topology	Protection
Shore (Trunk)		9										
Shore (Discrete)		9										
Global						3						
CONUS						11				1		
Region						32				3		
Intra-Unit		12				24				1		
High	12											
Basic	18											
Broadcast							35				3	
Hub/Spoke												
PTP			12				18				1	
Netted			18				17				1	
No Protection				12				25				3
Low				12				31				2
Medium				6				14				
High												
LDR					18							
MDR1					14				1			
MDR2					35				2			
HDR					3				2			
TOTAL	30	30	30	30	70	70	70	70	5	5	5	5
Odyssey	30	30	30	30	18	70	35	70				
Globalstar	30	30	30	30	18	70	35	70				
Teledesic					70	70	35	56	5	5	2	5
Military							35				3	

Table 7.2 MEU Links Supported by Commercial LEO Satellite Systems

4. Circuit Requirements for CVBG

Carrier battle group (CVBG) is a standing naval task group consisting of a carrier, surface combatants and submarines as assigned in direct support, operating in mutual support with the task of destroying hostile submarine, surface and air forces within the group's assigned area of responsibility and striking at targets along hostile shore lines or projecting fire power inland.

Suppose that MAGTF is supported by one CVBG. The circuits requirements for CVBG are shown in Figure 7.7 and are 300 for voice, 285 for data , and 20 for video services. In Table 7.3 shows that all voice and a part of data links can be established using Globalstar and Odyssey. Teledesic will provide also provide a part of the required video services.

F. SUMMARY

In this last chapter the potential role of LEO commercial satellite communication systems to military communications systems was examined and particularly to Marine Air-Ground Task Force. It was shown that these systems can provide all the required voice services and a significant part of data and video services. Therefore, it is beneficial for DoD to use these systems instead of investing heavily in new satellite systems. However, there are some issues that have to be investigated furthermore such as interoperability with existing military communication systems, priority, and security.

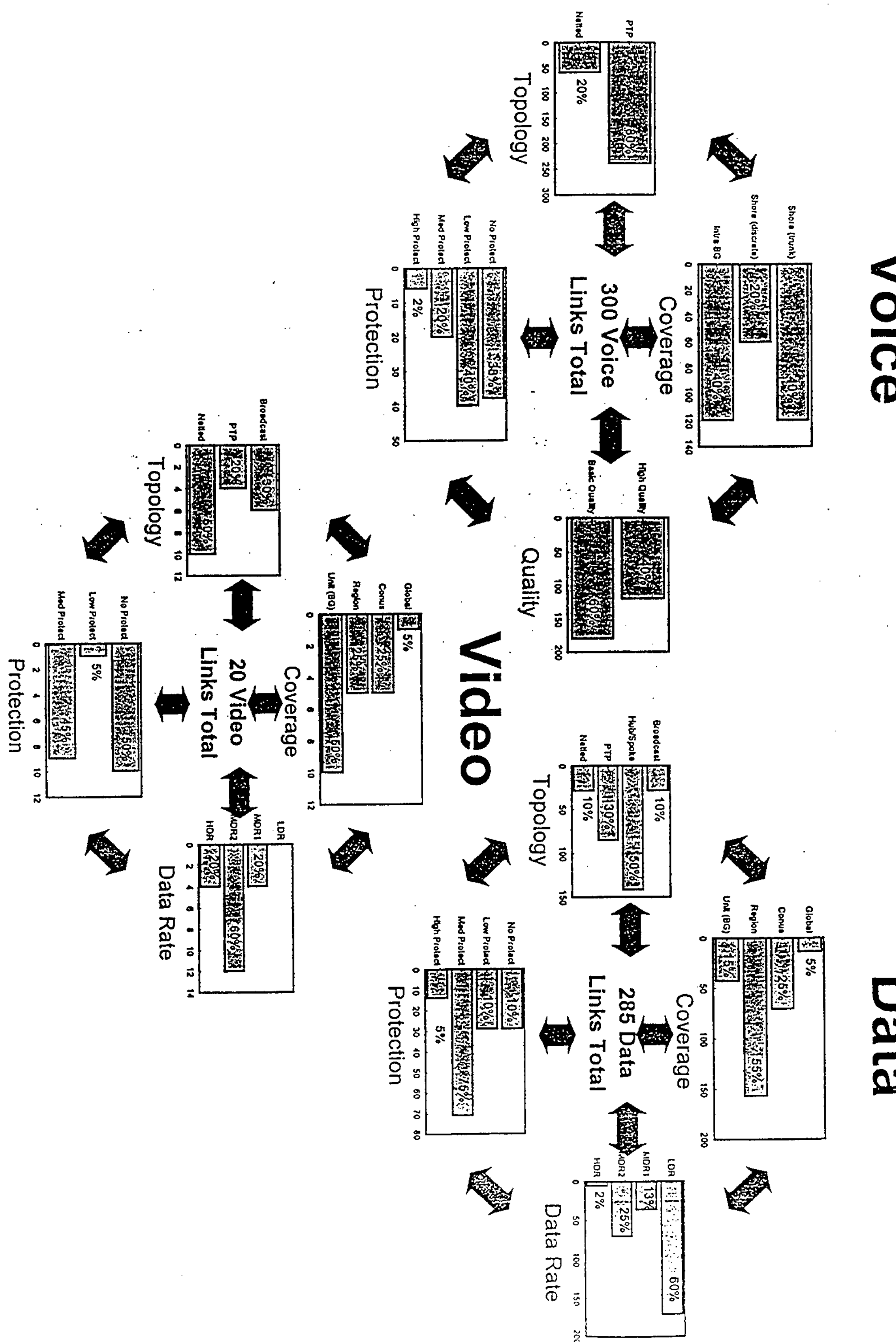


Figure 7.7 CVBG Circuits Requirements From Ref. [27]

	VOICE				DATA				VIDEO			
	Quality	Coverage	Topology	Protection	Data Rate	Coverage	Topology	Protection	Data Rate	Coverage	Topology	Protection
Shore (Trunk)		120										
Shore (Discrete)		60										
Global						14				1		
CONUS						71				5		
Region						157				5		
Intra-Unit		120				43				10		
High	120											
Basic	180											
Broadcast							28				6	
Hub/Spoke							143					
PTP			240				85				4	
Netted			60				29				10	
No Protection				114				28				10
Low				120				29				1
Medium				60				214				9
High				6				14				
LDR					171							
MDR1					37				4			
MDR2					71				12			
HDR					6				4			
TOTAL	300	300	300	300	285	285	285	285	20	20	20	20
Odyssey	300	300	300	234	171	285	257	271				
Globalstar	300	300	300	234	171	285	257	271				
Teledesic					285	285	257	57	20	20	14	11
Military				66	114		28	14			6	9

Table 7.3 CVBG Links Supported by Commercial LEO Satellite Systems

VIII. CONCLUSIONS

In this last chapter we summarize the conclusions made in the last two chapters. Without question there is a role for commercial mobile satellite communications in support of world-wide military operations. An effort by a Loral team showed that approximately 1/3 of the MSS DoD traffic is general purpose traffic which does not need to meet the full spectrum of MILSATCOM requirements (see Figure 8.1). The remaining 2/3 traffic is core traffic and has more stringent requirements. Commercial MSS systems can meet approximately 45% of the DoD MSS requirements, if the 11% of the core requirements are added to the general purpose traffic. [Ref. 4]

Commercial satellite PCS systems have the potential to satisfy military mobile communications needs that are currently satisfied by UHF military communications satellites. Transferring military UHF traffic to commercial satellite PCS systems frees up capacity on government systems that would be used to support additional mobile tactical users. Another benefit is possible cost reduction derived from use of commercial-off-the-self (COTS) products and from competitive service charges resulting from anticipated fierce competition in the PCS market. An example is the availability of commercial maintenance support and equipment warranties, which means that DoD does not have to establish unique and more costly operational and maintenance. Another benefit is military mobile users are provided with state-of-the-art commercial technology. [Ref. 10]

Conclusions are summarized as follows:

1. Commercial LEO/MEO satellite systems have the potential to provide

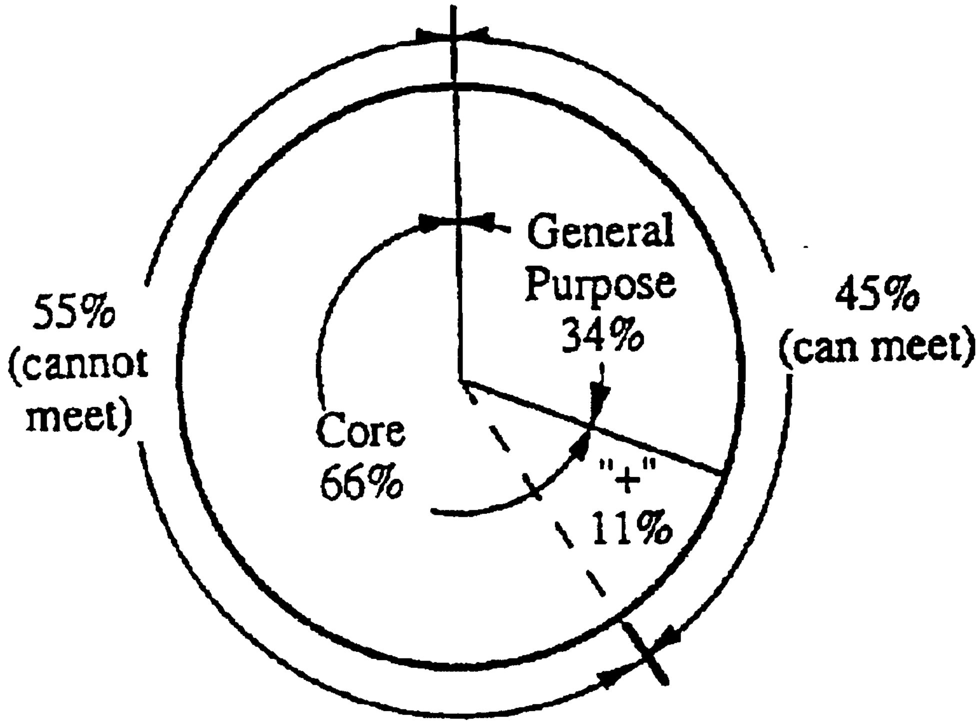


Figure 8.1 Mobile Satellite Services Traffic From Ref. [4]

communications support for DoD's less critical needs which include administration, logistics, and other support functions.

2. None of the commercial systems that were studied meets all the DoD requirements.

3. An architecture consisting of Odyssey and Globalstar meets the most of the criteria and government requirements for MSS services.

4. Teledesic is the only system to provide higher data rates (>64 Kbps) to mobile users operating directly with FSS systems.

5. Iridium is the only system to provide polar (north and south) coverage.

In previous chapter the potential role of LEO commercial satellite communication

systems to military communications systems was examined and particularly to Marine Air-Ground Task Force. It was shown that these systems can provide all the required voice services and a significant part of data and video services. Therefore, it is beneficial for DoD to use these systems instead of investing heavily in new satellite systems. However, there are some issues that have to be investigated furthermore such as interoperability with existing military communication systems, priority, and security.

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